Endodontically treated teeth: success and failure from a restorative perspective.

Jovito Adiel Skupien

Endodontically treated teeth: success and failure from a restorative perspective.

Thesis – Radboud University Nijmegen – with summary in Dutch and Portuguese

ISBN: 978-94-028-0198-9

Printed by: Ipskamp Drukkers, Enschede, the Netherlands

The research presented in this thesis is the result of the collaboration project between the Federal University of Pelotas, Graduate Program in Dentistry, Pelotas, Brazil and the Radboud University Medical Center, Department of Dentistry Nijmegen, The Netherlands.

Endodontically treated teeth: success and failure from a restorative perspective

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus,
volgens besluit van het college van decanen
in het openbaar te verdedigen op
maandag 11 juli 2016
om 14.30 uur precies

door

Jovito Adiel Skupien
geboren op 2 juni 1984
te São Luiz Gonzaga, Brazilië

Promotoren:
Prof. dr. M.C.D.N.J.M. Huysmans
Prof. dr. F.F. Demarco (Universidade Federal de Pelotas, Brazilië)

Copromotoren:
Dr. C.M. Kreulen
Dr. T. Pereira-Cenci (Universidade Federal de Pelotas, Brazilië)

Manuscriptcommissie:
Prof. dr. N.H.J. Creugers (voorzitter)
Prof. dr. F.J.M. Roeters (VU)
Dr. L.W.M. van der Sluis (UMCG)

“Try Not to Become a Man of Success. Rather Become a Man of Value.”

Albert Einstein

Original Publications

This PhD thesis is based on the following original publications.

1. Skupien JA, Kreulen C, Opdam N, Bronkhorst E, Pereira-Cenci T, Huysmans MC. Meta-analysis of survival studies on reconstruction of endodontically treated teeth. To be submitted.

2. Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. A practice-based study on the survival of restored endodontically treated teeth. J Endod. 2013;39(11):1335-40.

3. Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. Survival of restored endodontically treated teeth in relation to periodontal status. Braz Dent J. 2016;27(1):37-40.

4. Skupien JA, Kreulen C, Opdam N, Bronkhorst E, Pereira-Cenci T, Huysmans MC. Effect of Remaining Cavity Wall, Cervical Dentin, and Post on Fracture Resistance of Endodontically Treated, Composite Restored Premolars. Int J Prosthodont. 2016;29(2):154-6.

5. Skupien JA, Cenci MS, Opdam N, Kreulen C, Huysmans MC, Pereira-Cenci T. Crown vs. Composite for Post-retained Restorations: a Randomized Clinical Trial. J Dent. 2016;48:34-9.

List of contents

Chapter 1

Introduction, overall aim and outline of the PhD thesis

Severely traumatized teeth, usually through a succession of caries attacks and restorations, will often suffer pulp necrosis, resulting in pulpitis or periapical periodontitis. If such a tooth is to be maintained, endodontic treatment is the only possible option. The alternative, apart from accepting the missing tooth, would be a fixed prosthetic replacement or a dental implant. The choice between those treatment options is difficult. When well indicated, both types of procedures present adequate survival rates (1).

Generally, endodontic treatment is considered the less invasive method, preserving a natural root with its periodontal tissues. Endodontic treatment in itself is reported to be highly successful (2-5). However, it has been shown that a non-vital status (after endodontic treatment) is a very important risk factor for restoration failure (6,7). Why is it that endodontically treated teeth appear to be more vulnerable?

It has long been assumed that endodontically treated teeth (ETT) dry out and become more brittle. However, it was already demonstrated that endodontically treated teeth are not more brittle (8) and other factors should explain differences in longevity between vital and non-vital teeth. One possibility, as fracture is a common type of failure, may be found in the activities of chewing and clenching, as these are normally limited in force and duration by proprioception. Endodontic treatment, reduces proprioceptive tooth protection during mastication through removing all cellular and nerve content of the tooth (9), and as a result non-vital teeth are exposed to up to 60% higher occlusal forces when compared to vital teeth (10,11).

At the same time, ETT usually present a large coronal destruction due to caries or fracture, and the opening access necessary for the endodontic procedures, further reduces the amount of remaining dental tissue. Quantity and quality of dental structure are factors that must be taken into account if resistance of a tooth to fracture is evaluated (12,13), and a direct relationship between remaining dental tissue volume and capability to resist occlusal forces has been observed (14).

Even if restoration prognosis is lower in non-vital teeth, all teeth with an endodontic treatment still need a restoration. Irrespective of the procedure, a final restoration must provide a good coronal sealing and protect the remaining dental tissue, as well as restore form and aesthetic and occlusal function. The restoration should be placed as soon as possible after the endodontic treatment is finalized. Delayed coronal permanent restoration can negatively influence success rates.

Higher success rates in teeth with permanent restorations (amalgam, composite resin or crowns) were demonstrated than in teeth with temporary materials (15,16). Aquilino et al. showed that ETT not restored (with crowns or amalgam / resin composite definitive restorations) after obturation were lost at a 6.0 times greater rate than restored teeth (17). The importance of coronal coverage was well reported by Salehrabi and Rotstein (5). The authors retrospectively assessed the records of 1,462,936 teeth with endodontic treatment. After a period of 8 years, 97% of the teeth survived; however, within the 3% failures, complications occurred in teeth without any coronal coverage in 85% of the cases, demonstrating the importance of that factor on longevity.

Over the years, a large body of research has been devoted to finding the optimal restoration technique for ETT, with a focus on two aspects: (1) the need for a post, and the optimal material and configuration of the post, and (2) the need for full coronal coverage. With recent advances in adhesive dentistry, we see a gradual move towards minimally invasive techniques in a sense of applying fewer posts and crowns, preferred by leaving the post and adhesively placing restorations. Usually the alternative is direct restoration with composite resin.

Restorative dentistry using composite resin as a direct restorative material has increased in popularity in the past decades. Where initially the suitability of the material for posterior restorations was doubted, it is now the material of first choice in many countries. There is increasingly strong evidence that the performance of composite resin restorations in vital teeth is at least as good as amalgam (18-22). However, there is a lack of clinical evidence regarding the restoration of ETT. An example is a recent systematic review comparing the two most frequent types of restorations used to restore ETT, single crowns and composite resin restorations. The authors were forced to conclude that there is no sufficient evidence to preferentially choose one of the two treatments (23).

However desirable minimally invasive dentistry may seem, some issues are raised regarding behavior of large direct composite restorations without a post. The main function of a post is the retention of a core or coronal restoration. Meanwhile it is generally assumed that posts do not strengthen teeth, but may even weaken the root due to post space preparation. Whether a post is needed after all the procedures (caries removal and endodontic treatment) is based on the material loss of the tooth and how well the remaining tissue can support / retain the final restoration. Although in vitro studies showed that fracture resistance of ETT depends on factors such as adhesive material combination (24), type of restored tooth (25) and shape of the residual cavity (26), Mannocci et al. concluded that endodontically treated premolars restored with fiber post and direct composite or with metal-ceramic crowns had similar clinical success rates (27). Regarding endodontically treated canine teeth Ausiello et al. found that the most similar mechanical behavior to sound teeth was the combination of a composite crown and fiber post when compared with several other restorative approaches (28).The absence of a post did result in lower fracture resistance when molar teeth (metal crown restored) were evaluated (29), demonstrating that there may not be one optimal restorative approach for all ETT. Moreover, many post-related factors may influence their performance, such as the number of interfaces in the restored system, the post E-modulus and shape, and the type and thickness of the cement layer (30,31).

Traditionally, authors have claimed that only complete (cast) coverage of the clinical crown provides the necessary protection to ensure the clinical success of an endodontically treated tooth (32,33). However, crowns often require extra tooth preparation, removing sound tissue at the circumference of the tooth, thus weakening the core of the tooth. Besides, crown therapy can be expensive. A systematic review evaluated the success of ETT restored with crowns compared to direct restorations (composite resin, amalgam, and glass ionomer cements). The authors showed a 10-year success of 81% for crowns and 63% for direct restorations. The authors stated that direct restorations have a satisfactory survival only for a short period of time (34). However, most included studies were not Randomized Controlled Trials (RCT) and as restoration and tooth survival were combined in this study, finding the optimal restorative approach is then an elusive goal. Consequently, in clinical practice it seems that each condition should be evaluated individually, and advantages and disadvantages of all restorative possibilities should be assessed.

Overall aim and outline of the thesis.

It was the overall aim of this thesis to further explore the success and survival of restorations in ETT, with a focus on the question whether posts and full coverage crowns improve the prognosis, and if so, in what circumstances.

First of all we present a systematic review with meta-analysis on the survival of ETT, in relation to the presence of a post and the presence of a covering crown. A new statistical approach will be used, to transform cumulative survival data into Annual Failure Rate results, which can be combined over different studies.

Prospective clinical studies, and especially RCTs, are extremely rare in the evaluation of ETT, as failure rates are low, necessitating a long follow-up, and restorations are complicated and expensive. Also, it has been shown to be difficult to have operators follow the randomization protocol, as clinical opinions about the correct treatment choice may be strong (35). Retrospective clinical studies, university based or practice based, may be a partial substitute for prospective studies, especially where patients are loyal and follow-up in practice is long. We present a retrospective practice based study on the success and survival of restored ETT, evaluating both restoration as well as patient / dentition factors.

Retrospective studies looking at the success of restorations suffer from an irreparable flaw, namely indication bias. Any differences in survival between restoration techniques, such as the placement or omission of a post, or construction of a crown or direct restoration, may not be the result of differences in restoration quality or appropriateness, but of the different treatment choices made by the dentist. It is very likely that a dentist who places posts and crowns only in a subgroup of the ETT, will do so in the teeth with the more severe damage, and therefore the more compromised prognosis. Therefore, if we want to explore the need for posts and crowns, and their indication area, we have to turn to experimental study designs, as difficult as they may be. Critical situations to restore ETT were appraised in an in vitro study described in Chapter 5. Different cavity designs with various amount of remaining tooth structure in presence or absence of glass fiber post were submitted to thermal and mechanical fatigue to evaluate fracture resistance and fracture type of composite resin restorations.

Finally, it is aimed aimed to contribute to the highest level of scientific evidence in the indirect crown versus direct composite resin discussion, by reporting on an RCT, comparing survival of composite resin restorations and metal-ceramic crows in Chapter 6. All teeth received previously a glass fiber post and longevity and clinical performance was evaluated after 5 years of clinical service.

References

1. Setzer FC, Kim S. Comparison of long-term survival of implants and endodontically treated teeth. J Dent Res. 2014;93(1):19-26.
2. Balto K. Tooth survival after root canal treatment. Evid Based Dent. 2011;12(1):10-1.
3. Fleming CH, Litaker MS, Alley LW, Eleazer PD. Comparison of classic endodontic techniques versus contemporary techniques on endodontic treatment success. J Endod. 2010;36(3):414-8.
4. Pirani C, Chersoni S, Montebugnoli L, Prati C. Long-term outcome of non-surgical root canal treatment: a retrospective analysis. Odontology. 2015;103(2):185-93.
5. Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod. 2004;30(12):846-50.
6. van de Sande FH, Opdam NJ, Rodolpho PA, Correa MB, Demarco FF, Cenci MS. Patient risk factors' influence on survival of posterior composites. J Dent Res. 2013;92(7 Suppl):78S-83S.
7. Laske M, Opdam NJ, Bronkhorst EM, Braspenning JC, Huysmans MC. Longevity of direct restorations in Dutch dental practices. Descriptive study out of a practice based research network. J Dent. 2016;46:12-7.
8. Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod. 1992;18(7): 332–5.
9. Randow K, Glantz PO. On cantilever loading of vital and non- vital teeth. An experimental clinical study. Acta Odontol Scand. 1986;44(5):271-7.
10. Sedgley CM, Messer HH. Are endodontically treated teeth more brittle? J Endod. 1992;18(7):332-5.
11. Loewenstein WR, Rathkamp R. A study on the pressoreceptive sensibility of the tooth. J Dent Res. 1955;34(2):287-94.
12. Ellis SG, McCord JF, Burke FJ. Predisposing and contributing factors for complete and incomplete tooth fractures. Dent Update. 1999;26(4):150-2, 156-8.
13. Torbjörner A, Fransson B. A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont. 2004;17(3):369-76.

14. Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. Oper Dent. 1981;6(1):2-5.
15. Safavi KE, Dowden WE, Langeland K. Influence of delayed coronal permanent restoration on endodontic prognosis. Endod Dent Traumatol. 1987;3(4):187-91.
16. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. J Prosthet Dent. 2005;93(2):164-70.
17. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002;87(3):256-63.
18. van de Sande FH, Rodolpho PA, Basso GR, Patias R, da Rosa QF, Demarco FF, Opdam NJ, Cenci MS. 18-year survival of posterior composite resin restorations with and without glass ionomer cement as base. Dent Mater. 2015;31(6):669-75.
19. Naumann M, Koelpin M, Beuer F, Meyer-Lueckel H. 10-year Survival Evaluation for Glass-fiber-supported Postendodontic Restoration: A Prospective Observational Clinical Study. J Endod. 2012;38(4):432-5.
20. Femiano F, Femiano L, Femiano R, Lanza A, Lanza M, Rullo R, Perillo L. Class I restoration margin quality in direct resin composites: A double-blind randomized controlled clinical trial. Am J Dent. 2015;28(3):157-60.
21. van Dijken JW, Lindberg A. A 15-year randomized controlled study of a reduced shrinkage stress resin composite. Dent Mater. 2015;31(9):1150-8.
22. Opdam NJ, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, Gaengler P, Lindberg A, Huysmans MC, van Dijken JW. Longevity of posterior composite restorations: a systematic review and meta-analysis. J Dent Res. 2014;93(10):943-9.
23. Sequeira-Byron P, Fedorowicz Z, Carter B, Nasser M, Alrowaili EF. Single crowns versus conventional fillings for the restoration of root-filled teeth. Cochrane Database Syst Rev. 2015 Sep 25;9:CD009109.
24. Ausiello P, Davidson CL, Cascone P, DeGee AJ, Rengo S. Debonding of adhesively restored deep Class II MOD restorations after functional loading. Am J Dent. 1999;12(2):84–8.
25. Wendt Jr SL, Harris BM, Hunt TE. Resistance to cusp fracture in endodontically treated teeth. Dent Mater. 1987;3(5):232–5.

26. Cobankara FK, Unlu N, Cetin AR, Ozkan HB. The effect of different restoration techniques on the fracture resistance of endodontically-treated molars. Oper Dent. 2008;33(5):526–33.
27. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three- year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent. 2002;88(3):297-301.
28. Ausiello P, Franciosa P, Martorelli M, Watts DC. Mechanical behavior of post-restored upper canine teeth: a 3D FE analysis. Dent Mater. 2011;27(12):1285-94.
29. Santana FR, Castro CG, Simamoto-Júnior PC, Soares PV, Quagliatto PS, Estrela C, Soares CJ. Influence of post system and remaining coronal tooth tissue on biomechanical behaviour of root filled molar teeth. Int Endod J. 2011;44(5):386-94.
30. Coelho PG, Silva NR, Bonfante EA, Guess PC, Rekow ED, Thompson VP. Fatigue testing of two porcelain-zirconia all-ceramic crown systems. Dent Mater. 2009;25(9):1122–7.
31. Spazzin AO, Galafassi D, de Meira-Júnior AD, Braz R, Garbin CA. Influence of post and resin cement on stress distribution of maxillary central incisors restored with direct resin composite. Oper Dent. 2009;34(2):223–9.
32. Goerig AC, Mueninghoff LA. Management of the endodontically-treated tooth. Part II: Technique. The Journal of Prosthetic Dentistry 1983;49(4) 491-497.
33. Sorensen JA, Martinoff. Intracoronal reinforce- ment and coronal coverage: A study of endodontically-treated teeth. J Prosthet Dent. 1984;51(6) 780-4.
34. Stavropoulou AF, Koidis PT. A systematic review of single crowns on endodontically treated teeth. J Dent. 2007;35(10):761-7.
35. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent. 2007;35(10):778-86.

Chapter 2

Meta-analysis of survival studies on reconstruction of endodontically treated teeth

This chapter will be submitted for publication as:

Skupien JA, Kreulen C, Opdam N, Bronkhorst E, Pereira-Cenci T, Huysmans MC. Meta-analysis of survival studies on reconstruction of endodontically treated teeth.

Abstract

The aim of this study was to bring together published data on the clinical prognosis of reconstructed endodontically treated teeth with the type of restoration (crown or extensive composite restoration) and additional retention (post or no post) as factors. Following guidelines for reporting on systematic reviews and meta-analysis, an extensive search was conducted in the Cochrane Library and PubMed, resulting in 43 studies with traceable survival data. Thirty two of the selected studies observed the clinical behaviour of crowns and/or 16 studies studied composite restorations. Cast foundation restorations with posts were applied in 12 studies, fiber posts in 26 studies, and prefabricated metal post in 10 studies. Mean AFR for composite restorations seems to increase over time. For both crowns and composite restorations with posts AFR seems to decrease, or at least remains stable over the years. In case of no post, AFR is decreasing with the years. Ten year survival of restorations placed on ETT and restored with composite restorations, with or without post, was estimated to be 71% (95% CI 68.1 – 73.8%), while for crowns, with or without post, it is 82 % (95% CI 79.6 – 84.6%). After 10 years, failure of crowns reduces while for composites it remains at the same level. In case of ETT with posts, the restorations show favorable survival compared to restorations without post over the whole follow-up period of 17 years. Generally, all possibilities of reconstruction of an ETT showed acceptable survival rates, however, long-term evaluations seem to be in favour of crowns and the presence of a post.

Introduction

The endodontically treated tooth (ETT) presents a tooth with extensive loss of internal coronal tooth structure (Assif & Gorfil, 1994; Larson et al., 1981). Most often those teeth also face a substantial loss of external tooth tissue. Basically two restorative options, the direct or indirect restoration, are available for the reconstruction of the clinical crown of these teeth. The direct resin composite restoration serves simultaneously the core and crown build up of the reconstruction; retention is provided by adherence to tooth tissue. For the indirect lab-fabricated restoration, a separate foundation restoration is required besides the covering crown; friction and adherence is the retention mechanism of the crown.

The loss of internal tooth dentin after the endodontic treatment reduces the possibilities to create mechanical retention for the coronal restoration. To increase its retention endodontic posts are usually fitted to the root (Schwartz & Robbins, 2004). A drawback of this restorative procedure, however, is the required additional preparation of the root canal. It is anticipated that the volume of remaining tooth structure is one of the decisive factors for longevity of restored teeth, which complicates the practical decision to place a post or not (Nagasiri & Chitmongkolsuk, 2005). Obviously the conservative approach to be reluctant in removal of tooth tissue is attractive, despite the primary retentive advantages of a post.

The decision of the dentist to place a post is highly experience based since published information on the clinical functioning of ETT with or without posts is indefinite about their relative failure risks. Few studies report on 10-year findings or longer (Fokkinga et al., 2007; Jung et al., 2007; Naumann et al., 2012), while the majority of studies represent weaker clinical evidence due to short follow-up and relative small numbers of samples. As a consequence there is a lack in clinical protocols of how to reconstruct the ETT.

In order to connect the results of several small studies, systematic reviews on ETT with different restorative approaches have been published (Bolla et al., 2007; Figueiredo et al., 2015; Ploumaki et al., 2013). None of these established a prognosis of the ETT based on the type of restoration (direct or indirect) and the use of posts (yes or no). Therefore, the aim of this study was to bring together published data on the clinical prognosis of reconstructed endodontically treated teeth with the type of restoration (crown or extensive composite restoration) and additional retention (post or no post) as factors.

Material and methods

Overall inclusion

With the literature search we selected randomized controlled trials (RCT), prospective clinical trials (PCT), and retrospective clinical studies (RCS) that reported longevity data on endodontically treated teeth (ETT) with reconstruction of the clinical crowns in humans. The treatment of interest was the reconstruction of a tooth after elected endodontic treatment that included the management of the post space area of the root canal, the build-up of the core of the tooth and the restoration of the anatomical form of the crown. Inclusion was directed to reconstruction of the teeth with indirectly fabricated covering single crowns or directly placed resin composite restorations. Papers were excluded when the following information was not clear: size of the study, follow-up time, type of post and/or restoration, and number of failures. If the reconstructed tooth was an abutment or the direct restoration was not made of composite, or if results could not be traced to distinct samples, the study was not included.

Search strategy

Papers published in the period January 1990 till November 2014 were searched in the electronic databases PubMed (www.ncbi.nlm.nih.gov) and The Cochrane Central Register of Controlled Trials (www.cochrane.com). The search strings were first restricted to Mesh terms in the combination '(((endodontically treated or nonvital) and (teeth or tooth)) and (restoration or longevity or failure))'. In a second phase, the indicated Mesh terms were used as free text words. The digital search was performed from a campus network in the period April 2013 to June 2013 and was updated in November 2014. Results of each search were stored in separate files and those were compared in a second step to exclude double or triple references.

Screening and Selection

Further selection was performed in a two step procedure. Firstly, title and abstract of the resulting references were printed on paper and two reviewers (JAS and TPC) selected independently references based on the inclusion criteria regarding the type of clinical paper and the language of publication (English, Portuguese, Dutch). The two judgments for each reference were compared, observer agreement was determined and in case of disagreement a joint decision was forced. If no agreement could be reached, a third reviewer (CK) decided upon selection.

Secondly, full text copies of the eligible references were printed and the two reviewers deselected references based on the in- and exclusion criteria using consensus selection. The search update for the period June 2013-November 2014 followed the same procedure and selected papers were entered in the full-text reading. Additionally, the references lists of the selected papers was screened for references that were missed by the digital search. These papers were added to the list of references and their eligibility was assessed separately using the same criteria.

Of each included paper, study characteristics were extracted from the Material and Methods sections. Results sections were screened for data on the performance of the reconstructed ETT to fit a meta-analysis. Data were standardized recorded on a data extraction form. Ten percent of the papers was checked for excavating the appropriate data by the third reviewer. Hereafter, studies were excluded that reported on ETT as abutment in fixed or removable partial dentures (FPD/RPD) and ETT directly restored with a material other than composite. The data of studies with branches including ETT both as single crowns and as abutments were split, to result in data of the single crowns only. Splitting was also done for studies that observed both composite restorations and other restorative materials, to arrive at the data for the composites only. If splitting was not possible, the study was excluded. If more than one of the selected papers was published on the same clinical study, the paper with the data of the longest follow-up or the paper with the most extensive data description was used.

Outcome variables

Screened primary outcome variable in each paper was survival of the restorations, expressed as annual failure rate (AFR). AFR is an indicator of risk of failure per year. If the AFR remains constant over time, the survival graph will be a hyperbolic graph because the number of failures per unit of time will drop due to the decreasing number of teeth in function. The published AFR per study was recorded for each observation year of the particular study. This was done separately for each of the subsequent four reconstruction types: ETT with crowns with or without posts and for ETT with composite restorations with or without posts. If paper(s) reported distinct AFRs for different time intervals of one study, these AFRs were recorded accordingly. Using AFR per year it was taken that within the one-year interval, failure risk was regarded constant.

The study to be included should report the relation between failures and time as an unambiguous failure rate or the failure rate could be derived. For this derivation Kaplan Meier (KM) survival rates, whether reported or plotted from the KM graph in the paper, and life-table style analyses could be used. Studies just reporting a number of failures over a period of time, without consideration of censoring, were excluded. If the failure rate was reported over a period of more than one year, the mean AFR over that period was calculated by the mathematical compound interest formula:

$$AFR = 1 - \sqrt[period]{1 - frac\ survived}$$

1) AFR is Annual Failure Rate over the specific interval
2) frac(tion) survived is the number of restorations at the end of the interval divided by the number of restorations at the beginning
3) period is the number of years of the interval as the denominator of the fractional exponent.

In clinical reports survival of reconstruction of a tooth ends with repair or a more invasive treatment. In this meta-analysis no attempt was made to differentiate between types of failure, because often the authors of the included studies did not clarify the nature of the failures observed in their study.

Statistical analysis

Observer agreement in the selection process of the two reviewers was determined by Kappa-coefficient. Content quality of the selection process was checked and confirmed by the third reviewer.

With the reported or calculated AFRs per study it was not possible to calculate a mean AFR for all studies due to studies with variable AFR during their follow-up and due to a range of duration of the included studies. To arrive at an overall AFR, we used the mathematical procedure according to van Oirschot et al. (2013). Of the recorded yearly AFRs of the studies for each of the four reconstruction types, we first calculated the weighted mean AFR per year. For the years covered by the study with the shortest follow-up, all studies including one or more of the four reconstruction types provided AFRs , while the volume of data decreased reaching the observation period of the study with the longest follow up. The weighted mean AFR per year and its pooled standard error was estimated by meta-analysis in the R statistics, version 3.1.2 (www.R-project.org). Weighing factor was the inverse variance of each study based on the standard 95% confidence interval calculation of proportions for its AFR. If the R-test for homogeneity of variances between a study result and the mean AFR exceeded the level of 0.05, the variance of the particular study was estimated by the heterogeneity variance added with the pooled variance of the mean AFR (DerSimonian and Laird, 1986). Per type of reconstruction a funnelplot was constructed to explore publication bias. In these graphs the inverse of the standard error (as an indication of the measurement precision and of study size) was depicted to AFR for each study. In the graph the most robust studies are in the top. Symmetric funnels cannot be expected since values lower than AFR=0 are not possible, triangles will be the result.

The precision of the estimates of the mean AFRs will decrease with increasing observation time due to a lower number of long lasting studies. Moreover, variance in AFR may be present in small studies due to the substantial effect of one additional failure on a limited number of restorations. Since AFR as a proportion is in itself a chance variable, combined with the substantial variance of the reported AFRs, calculation of the 'population' mean AFRs with standard errors of the mean is near impossible. To our information statistical methods are lacking to combine sequential mean AFRs per year with their standard errors into a survival curve.

We therefore added information of uncertainty to the estimates of the level of survival over time by a simulation procedure, which has been described earlier (van Oirschot et al, 2013). This procedure is identical for all reconstruction types and consisted of three steps to obtain the best possible survival estimate. First, each meta-analysis yielded an AFR and its s.e. per reconstruction type for each year. Before simulating, a distribution per year was generated, which can be seen as digital dice deciding on 'failure or not'. The mean chance of failure as given by the dice was evidently the AFR for a given year, and the spread around that chance was dictated by the s.e. of the AFR.

Next, a 'population' of 1000 samples (ETT) was subjected to a 1000 throws of the dice for year 1. This resulted in a fraction of ETT considered as failed, approximately to the level of the AFR. This was repeated for the remaining ETT, using the simulated AFR dice for year 2. So year by year, the ‘population’ ETT decreased. On average this followed the AFRs for the successive years, but not exactly. Because failure itself is a process of chance and the chances of failure itself (the AFRs) are subjected to uncertainty, this process will not exactly result in a fraction to the size of the yearly AFR.

Hence, in the third step the previous process was repeated 1000 times. These 1000 simulations, each following 1000 ETT over time, provided the level of uncertainty. By looking at the lowest 2.5% and highest 97.5% survival for these 1000 simulations, a 95% confidence interval was obtained. These intervals were added to the survival curves for each reconstruction type.

Results

Screening and selection

The electronic literature search for papers on longevity of endodontically treated teeth (ETT) with reconstruction of the clinical crowns using the given search strings produced 1250 hits, Figure 1 shows the flow-diagram. First double or triple references were excluded, then 34 references were excluded because the language of publication did not meet the three languages applied in this review (18 Chinese, 9 German, 4 French, 2 French/German, and 1 Japanese).

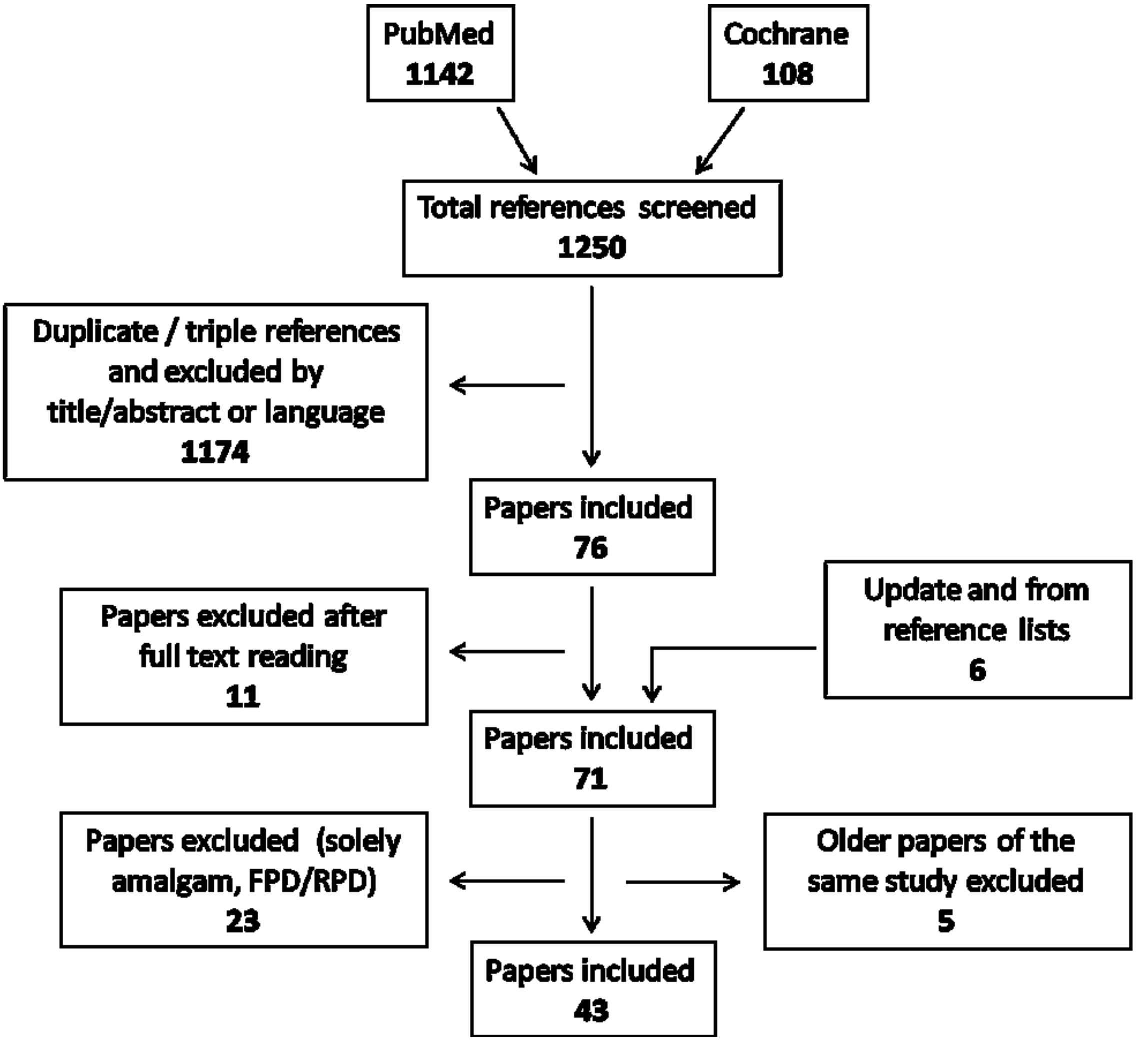

Figure 1 - Flowchart of the selection process, with the numbers of the concerned papers in each textbox.

By selection done by the two reviewers on the basis of title and abstract 1174 of 1250 references were excluded for not reporting on a clinical study, or being duplicates/triples. The inter-observers agreement of this step in the selection procedure was performed with Kappa=0.94, all cases of disagreement could be solved without judgment of the third reviewer.

From the full-text examination of the 76 eligible references by the two reviewers by consensus using the stated criteria, 65 papers remained. Reasons of excluding were the paper not stating information like the size of the study, the follow-up time, the type of post and/or restoration, or the number of failures. In a parallel branch, screening of the references lists of the included papers for hidden references revealed eight extra papers not identified before, of which none was eligible for this review. From the update search followed by the identical selection procedure, 10 papers were read full-text of which six could be added to the 65 papers.

Three papers studied solely amalgam reconstruction of ETT (Ahrari et al. 2010; Hansen et al., 1990a; Shafiei et al., 2010) and in one study only FPDs with ETT (De Backer et al., 2008) were subject of study. Excluding those four papers, 67 remained. For reason of the impossibilities to calculate AFR, to discern single crowns from abutments in studies with branches that included ETTs as part of FPD/RPDs, to distinguish restorations with and without post, or to differentiate between on- and inlays, 19 studies were additionally excluded (Aquilino & Caplan, 2002; Bandlish & Mariatos, 2009; Chrepa et al., 2014; Dammaschke et al., 2013; Ferrari et al., 2000a; Fredriksson et al., 1998; Gomez-Polo et al., 2010; Hedlund et al., 2003; Hikasa et al., 2010; Mentink et al., 1993a and 1993b; Murgueitio & Bernal, 2010; Paul & Werder, 2004; Salvi et al., 2007; Schmitter et al., 2007; Segerström et al., 2006; Skupien et al., 2013; van Dijken et al., 2001; Walton, 1999).

Five of the included studies were each described by 2 follow-up reports, for four of these studies the most recent report was selected (Creugers et al., 2005a and Fokkinga et al., 2007; Creugers et al., 2005b and Fokkinga et al., 2008; Naumann et al., 2005 and Naumann et al., 2012; Cagidiaco et al., 2008 and Ferrari et al., 2012) and for the fifth the earlier was selected, because in the newer report single crowns and FDP/RPDs could not be distinguished (Naumann et al., 2007 and Sterzenbach et al., 2012).

Study outcomes

Table 1 shows the 43 remaining studies with traceable survival data (with their branches that included composite restorations and/or crowns), reporting type of study, sample size, type of post(s), period of study, and recalculated AFRs. Over a third of the studies were randomized controlled clinical trials (RCT), about a third were prospective clinical trials (PCT), and just less than a third were retrospective clinical studies (RCS). Thirty two of the selected studies observed the clinical behaviour of crowns and/or 16 studies studied composite restorations. Cast foundation restorations with posts were applied in 12 studies, fiber posts in 26 studies, and prefabricated metal post in 10 studies. Posts were omitted in 14 study branches. The mean study size was 127 ETTs, with a minimum of 20 and maximum of 526 ETTs. The total number of included composite restorations was 1844 and 4290 crowns were involved. Posts were applied in 4435 reconstructed ETT and posts were omitted in 1699 cases. Observation periods ranged from 0.5 to 17 years. Published, calculated or estimated AFRs ranged from 0 to 16.3 %. For some studies a range has been depicted: this means that different AFRs were found for each of the study branches. Studies were performed in university clinics with the restorations made by students or staff and in general or specialized dental practices.

Meta analysis

The meta-analysis was divided into several meta-analyses that were directed to longevity of the four types of reconstruction of ETT, grouped into the type of restoration (composite and crown) and the presence of a post (post and no post). Some studies studied more than one group of reconstructions. Although the differentiation within the variable type of restoration into post/no post was not a level of analysis, the numbers of the included studies and branches, indicated as substudies, is helpful and they were:

1. Crown without post; 7 (sub)studies, N = 398
2. Crown with post; 31 (sub)studies, N = 3892
3. Composite restoration without post; 8 (sub)studies, N = 1301
4. Composite restoration with post; 9 (sub)studies, N = 543.

Table 1 - General characteristics of the 43 included papers, in the sequence of year of publication of the reports

Study (1st author, yr)	Study design*	Nr. included teeth	Type of post*	Type of restoration	Follow-up (years)	Lowest - highest AFR
Hansen 1990b	Retrospective	189	NoP	Comp	10	2.4 % - 3.7 %
Hatzikyriakos 1992	Prospective	54	Cast / MP	Crown	3	0 – 3.0 %
Torbjörner 1995	Retrospective	475	Cast / MP	Crown	3.2	3.2 %
Sjogren 1999	Retrospective	40	Cast /MP	Crown	6.1	1.3 – 1.9 %
Glazer 2000	Prospective	27	FP	Crown	2.3	4.9 %
Ferrari 2000b	RCT	195	Cast / FP	Crown	4	0.5 – 3.7 %
Näpänkangas 2000	Retrospective	111	Cast	Crown	6.5	2.1 %
Mannocci 2002	RCT	107	FP	Crown / Comp	3	1.9 – 2.6 %
Ellner 2003	RCT	50	Cast / MP	Crown	8.6	0 – 2.6%
King 2003	RCT	23	Cast / FP	Crown	7.3	3.3 %
Malferrari 2003	Prospective	180	FP	Crown	2.5	0.7 %
Monticelli 2003	RCT	225	FP	Crown	2	2.7 – 4.1 %
Lynch 2004	Retrospective	95	Cast / NoP	Crown / Comp	3.2	2.7 – 5.7 %
Grandini 2005	Prospective	100	FP	Comp	2.5	0 %
Mannocci 2005	RCT	97	FP	Comp	5	2.2 %
Nagasiri 2005	Retrospective	195	NoP	Comp	5	4.0 – 25 %
Can Say 2006	Prospective	39	NoP	Comp	2	0 %
Adolphi 2007	Retrospective	44	NoP	Comp	6.8	3.4 %
Balkenhol 2007	Retrospective	412	Cast	Crown	7.3	5.1 %
Cagidiaco 2007	Prospective	162	FP	Crown / Comp	2	0 - 5.1 %
Ferrari 2007	RCT	240	FP / NoP	Crown	2	3.8 – 16.3 %
Fokkinga 2007	RCT	307	Cast / MP / NoP	Crown	17	0.8 – 2.0 %
Jung 2007	Retrospective	34	Cast / MP	Crown	8.6	0 – 0.6 %
Naumann 2007	RCT	52	MP / FP	Crown	2.3	0 %
Piovesan 2007	Retrospective	110	FP	Crown / Comp	8.1	0.3 – 0.9 %
Fokkinga 2008	RCT	98	MP / NoP	Comp	17	3.2 - 4.1 %
Preethi 2008	Prospective	30	Cast / FP	Crown	1	0 – 0.1 %
Ayna 2009	Prospective	65	FP	Comp	3	0 %
Bitter 2009	RCT	102	FP / NoP	Crown / Comp	2,7	0 – 5.3 %
Deliperi 2009	Prospective	35	NoP	Comp	1	0 %
Signore 2009	RCT^	526	FP	Crown	5.3	0.5 %
Bernhart 2010	Prospective	20	NoP	Crown	2	5.1 %
Mancebo 2010	Prospective	87	FP	Crown	2.8	6.1 %
Ghavamnasiri 2011	Retrospective	43	FP	Comp	3.9	8.1 %
Signore 2011	Prospective	154	FP	Crown	3.5	1.3 %
Zicari 2011	RCT	205	Cast / FP / NoP	Crown	1.8	0 – 2.2 %
Ferrari 2012	RCT	360	FP / NoP	Crown	6	5.9 – 13.4 %
Jongsma 2012	RCT	43	NoP	Crown	3	6.2 %
Naumann 2012	Prospective	79	FP	Crown	6.2	8.1 %
Memarpour 2013	Prospective	48	FP	Comp	2.5	1.7 %
Gbadebo 2014	RCT	40	MP/ FP	Crown	0.5	0 – 9.8 %
Julosky 2014	RCT	120	FP	Crown	4	6.9 %
Sarkis-Onofre 2014	RCT	72	Cast / FP	Crown	3	1.0 – 2.8 %
	* Randomized Clinical Trial ^ randomis-ation not 'type of post' or 'restoration'		* P&C: Cast post-core MP: Metal Post FP: FiberPost NoP: No Post	* Comp: Composite		

In Table 2 the weighed mean AFRs per year and their standard errors per reconstruction type are shown as the results of the 68 meta-analyses. Mean AFR for composite restorations seems to increase over time. For both crowns and composite restorations with posts AFR seems to decrease, or at least remained stable over the years. In case of no post, AFR decreased with the years. Homogeneity of the AFRs of the studies was rejected in 5 out of the 68 cases. The funnelplots per type of reconstruction in Fig. 2 indicate that it is unlikely that publication bias was present, since most of the data points are in the upper half of the graph and the figures resemble triangles.

Table 2 - Weighed mean AFRs per year and their 95% confidence interval for the two reconstruction types and for the restorations with or without post, as based on 17 meta-analyses per category

	Composite		Crown		With Post		No Post	
Year	**Meta AFR**	**Meta s.e.**	**Meta AFR**	**Meta s.e.**	**Meta AFR**	**Meta s.e.**	**Meta AFR**	**Meta s.e.**
1	1,36%	0,47%	2,70%	0,39%	1,55%	0,22%	4,36%	1,18%
2	1,45%	0,50%	2,59%	0,39%	1,50%	0,23%	4,91%	1,26%
3	3,86%	1,39%	1,56%	0,26%	1,37%	0,24%	7,29%	2,61%
4	5,66%	2,22%	2,28%	0,55%	1,33%	0,29%	7,99%	3,31%
5	5,07%	2,14%	1,26%	0,32%	1,23%	0,32%	7,69%	3,07%
6	2,99%	1,19%	2,77%	0,58%	2,60%	0,58%	3,83%	1,24%
7	2,96%	1,21%	2,12%	0,64%	2,12%	0,63%	3,13%	1,32%
8	2,91%	1,29%	2,07%	0,71%	2,07%	0,69%	3,09%	1,41%
9	3,67%	1,51%	1,02%	0,92%	1,19%	0,94%	3,06%	1,45%
10	3,67%	1,53%	1,08%	0,99%	1,27%	1,00%	3,06%	1,46%
11	3,58%	2,96%	1,08%	0,99%	1,27%	1,01%	1,72%	2,57%
12	3,58%	3,01%	1,08%	1,00%	1,27%	1,02%	1,70%	2,60%
13	3,57%	3,06%	1,08%	1,01%	1,26%	1,03%	1,68%	2,63%
14	3,57%	3,11%	1,08%	1,01%	1,26%	1,03%	1,67%	2,66%
15	3,57%	3,17%	1,08%	1,02%	1,26%	1,04%	1,65%	2,69%
16	3,54%	3,32%	1,07%	1,03%	1,26%	1,05%	1,53%	2,77%
17	3,53%	3,37%	1,07%	1,04%	1,25%	1,06%	1,51%	2,80%

The results of the simulation procedure are shown in Fig. 3 as survival curves. Ten-year survival of restorations placed on ETT and restored with composite restorations, with or without post, was estimated to be 71% (95% CI 68.1 – 73.8%), while for crowns, with or without post, it is 82 % (95% CI 79.6 – 84.6%) (fig. 3a and 3b). In the short run this difference is not so obvious. After 10 years, failure of crowns reduces while for composites it remains at the same level. In case of ETT with posts, the restorations show favorable survival compared to restorations without post over the whole follow-up period of 17 years. Ten-year survival for restorations with posts is estimated to be 85% (95% CI 82.8 – 87.0%) and AFR seems to be very constant. If the post is omitted ten-year survival is estimated to be 61% (95% CI 57.9 – 63.9%) after some years with a quite steep curve.

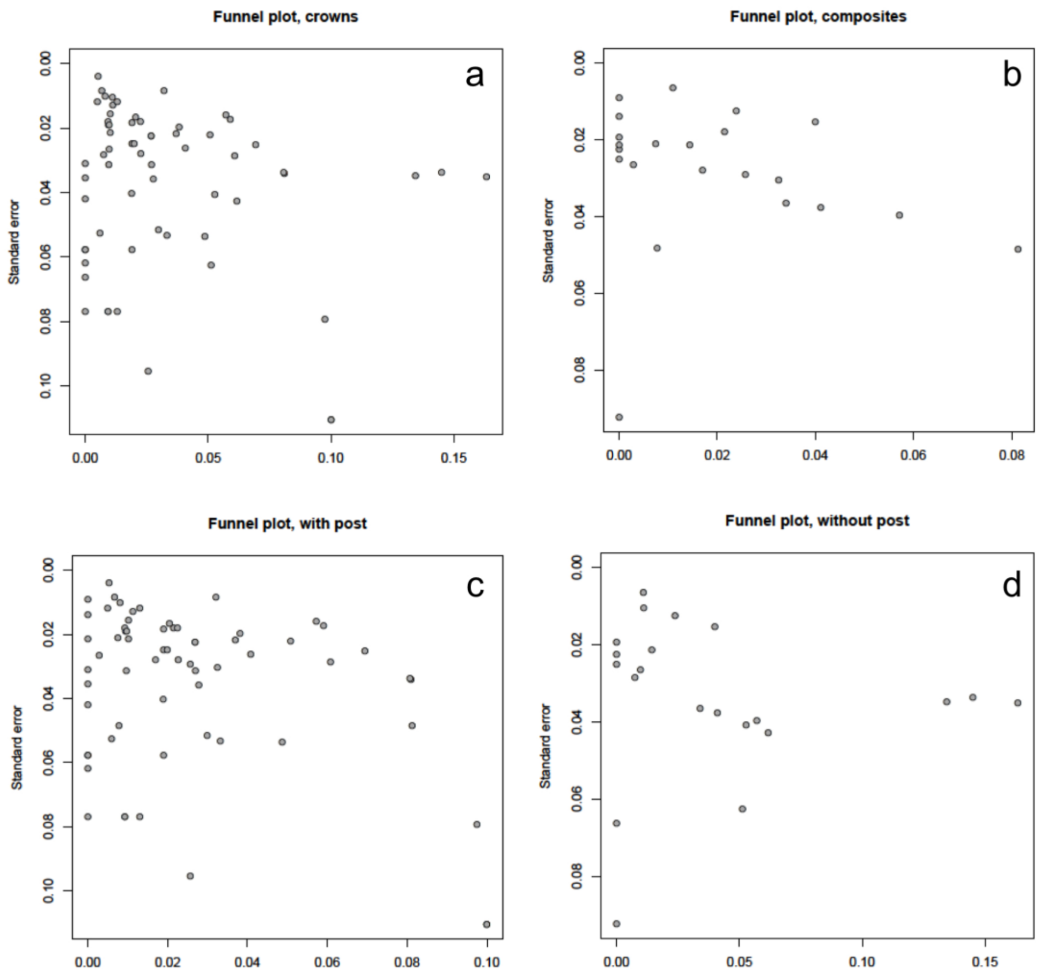

Figure 2a-d – Funnel plots on the basis of AFR and inverse standard error for the four reconstructions. The graphs resemble triangles with the upper half of the graph filled, indicating low risk of publication bias.

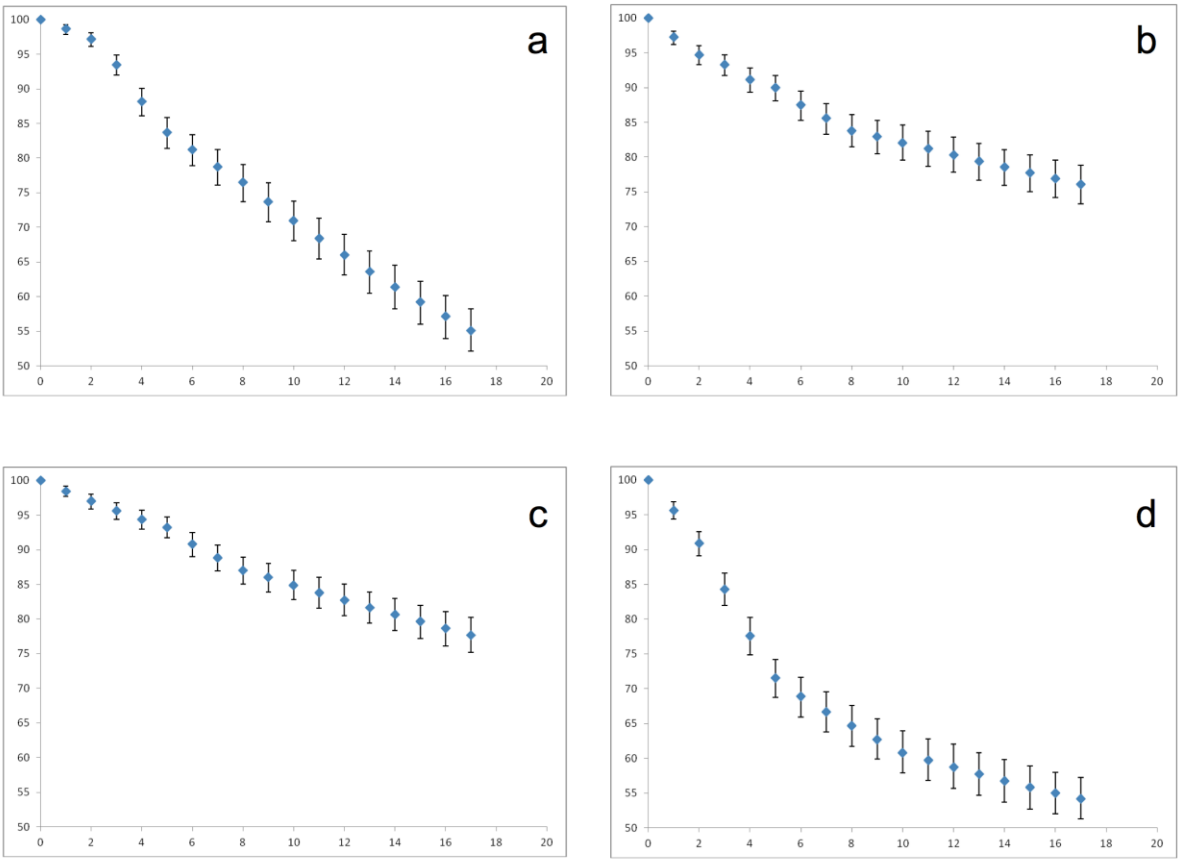

Figure 3a-d - Survival curves for the four types of reconstructions of ETT: a. composite restorations (with/without post); b. crowns (with/without post); c. restorations (composite/crowns) with post; d. restorations (composite/crowns) without post.

Discussion

The clinical decision of a dentist to how to restore an endodontically treated tooth (ETT) is most often based on the volume of lost tooth tissue and the estimated risk of fracture of the remaining tooth structure (Patel & Barnes, 2013). The goal is to obtain a long surviving reconstruction and the topical question in practice is whether the traditional crown restoration and the current adhesive approach differ regarding this outcome. To our knowledge nearly a dozen systematic reviews have been performed to bring together the data of RCTs regarding the survival of reconstructed ETT (Barfeie et al., 2015; Bolla et al., 2007; Fedorowicz et al., 2012; Figueiredo et al., 2015; Goodacre, 2010; Heydecke & Peters, 2002; Ploumaki et al., 2013; Sequeira-Byron et al., 2015; Stavropoulou & Koidis, 2007; Yang et al., 2015; Zhu et al., 2015). Since those reviews had limited data to process, the goal of the present meta-analysis was to bring together the maximum of survival data that could reliably be found in the dental literature regarding restored ETT.

Apart from RCTs, we extended the search to longevity data from pro- and retrospective studies, even without comparison of treatment modalities. Obligatory was that the number of treated teeth at baseline was known, that the treatment protocol and dental materials within studies were standardized, that failures per year were registered, and that individual follow-up could be traced. Missing intention-to-treat declarations in RCTs were no reason for exclusion and confounder check in case of cohort studies was omitted. We accepted study reports that reported crude survival rates on the condition that total failures over the period of follow-up could be recalculated to annual failure rate. Besides, the type of failure was not a unit of analysis in the present meta-analysis. Being not too restrictive in acceptance of studies increased the likelihood to include high numbers of studies, actually 6130 reconstructions were included. The balance of this strategy is a high risk of heterogeneity, both clinical and statistical.

The applied treatment procedures in the included studies were common practice, we therefore regarded those as clinically homogenous. Differences in handling instructions or materials choices between clinical protocols were not considered critical factors as long as scientific data do not indicate that those differences might dictate survival. This applies for instance to the use of rubberdam in adhesive procedures or the choice between carbon or glass fiber posts. The check for statistical heterogeneity indicated that the difference in survival between studies was no reason to exclude studies afterwards, although 3 studies showed AFRs larger than 10%. Heterogeneity could be introduced by differences in the criterion 'failed restoration'. Few of the included studies reported on calibration of the evaluators, let alone description of the end of lifetime. Bias by indication of failure is probable and, like the treatment procedures, we had to rely on common clinical practice in this respect.

Using overall failure rate might neglect changing survival rate during follow-up. The applied statistical method in this meta-analysis is a self developed method to model survival functions based on the recalculation of AFRs per study over the full observation period (van Oirschot et al, 2013). This is followed by meta-analyses of AFRs per year. AFR is subjected to uncertainty and we consider the modelling of survival in a simulation study adequate to estimate both the variance of the mean yearly survival rate and the upper and lower bound of the 95% confidence interval of survival over time.

From the selection procedure it appeared that 18 of the excluded papers by language, were Chinese. This is an indication that it is desirable that data on ETT from this part of the world be better uncovered. Furthermore we expected that more than the 5 studies found had follow-up papers. This is certainly not a negative feature, since the results of short-term interim reports might not be a valid indication of long term clinical survival. Looking at the duration of the studies, the medium term study (5-7 years) is quite frequently selected.

The present review showed the importance of long-term evaluation. In the first 2 to 3 years ETT with composite restorations seems to perform better than ETT with crowns, disregarding the presence or absence of posts. However, in the final evaluation the discrepancy is vice versa. The results of the present meta-analyses indicated that the restorations of ETT reconstructed with a crown have a better long-term prognosis if composite restorations are used. This is in agreement with a systematic review that stated that ETT restored with crowns show an acceptable long-term survival of 10 years, while direct restorations have a satisfactory survival only for a short period (Stavropoulou and Koidis, 2007). From the one RCT that was included in a Cochrane-review it was concluded that there was insufficient reliable evidence to determine whether single crowns were better than routine fillings (Sequeira-Byron et al., 2015). In general practice it was even found that for survival of the tooth, the ETT can be better restored with a composite restoration than with a crown (Skupien et al., 2013).

The importance to distinguish restorations with or without post is clear from our results, with better longevity for restorations with post. Only seven studies compared survival of restorations with post to restorations without post within their studies. Two of the RCTs found better survival of restorations with posts (Ferrari et al., 2007; Ferrari et al., 2012), while four RCTs did not (Fokkinga et al., 2007 and 2008; Bitter et al., 2009; Zicari et al., 2011). However, in a retrospective practice-based study it was found that ETT restorations with posts had lower survival than those without (Skupien et al., 2013). A recent meta-analysis included three of these RCTs, observing fiber posts and no post, and concluded that the risk for catastrophic failure was greater for non-post restorations than for restorations with a post (Zhu et al, 2015). In our study the type of failure could not be recorded and due to the complexity of our statistical approach, it was not feasible to perform subgroup analyses. The recent meta-analysis studying metal versus fiber posts, concluded that no difference in fracture behaviour could be found between those two types of post (Figueiredo et al., 2015).

Given the multifaceted reconstructive features of an ETT, it seems that each situation for clinical decisions should be evaluated individually and all the restorative possibilities discussed with the patient. An ETT with substantial remaining dentin does not seem to be in need a post, while the more dentin has been lost, the more a post is indicated (Skupien et al., 2016). The indication of a crown or composite restoration is less clear and we still need the results of RCTs to support our decision. Generally, all four possibilities of reconstruction of an ETT showed acceptable survival rates, however, long-term evaluations seem to be in favour of crowns and the presence of a post.

References

Adolphi G, Zehnder M, Bachmann LM, Göhring TN. Direct resin composite restorations in vital versus root-filled posterior teeth: a controlled comparative long-term follow-up. Oper Dent. 2007;32(5):437-42.

Ahrari F, Nojoomian M, Moosavi H. Clinical evaluation of bonded amalgam restorations in endodontically treated premolar teeth: a one-year evaluation. J Contemp Dent Pract. 2010;14;11(5):009-16.

Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002;87(3):256-63.

Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent. 1994;71(6):565–7.

Ayna B, Celenk S, Atakul F, Uysal E. Three-year clinical evaluation of endodontically treated anterior teeth restored with a polyethylene fibre-reinforced composite. Aust Dent J. 2009;54(2):136-40.

Balkenhol M, Wöstmann B, Rein C, Ferger P. Survival time of cast post and cores: a 10-year retrospective study. J Dent. 2007;35(1):50-8.

Bandlish LK, Mariatos G. Long-term survivals of 'direct-wax' cast gold onlays: a retrospective study in a general dental practice. Br Dent J. 2009;8;207(3):111-5.

Barfeie A, Thomas MB, Watts A, Rees J. Failure Mechanisms of Fibre Posts: A Literature Review. Eur J Prosthodont Restor Dent. 2015;23(3):P115-27.

Bernhart J, Bräuning A, Altenburger MJ, Wrbas KT. Cerec3D endocrowns--two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars. Int J Comput Dent. 2010;13(2):141-54.

Bitter K, Noetzel J, Stamm O, Vaudt J, Meyer-Lueckel H, Neumann K, Kielbassa AM. Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: preliminary results of a mean period of 32 months. J Endod. 2009;35(11):1477-82.

Bolla M, Muller-Bolla M, Borg C, Lupi-Pegurier L, Laplanche O, Leforestier E. Root canal posts for the restoration of root filled teeth. Cochrane Database Syst Rev. 2007;24:(1):CD004623.

Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M. Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. Int J Prosthodont. 2007;20(3):293-8.

Cagidiaco MC, García-Godoy F, Vichi A, Grandini S, Goracci C, Ferrari M. Placement of fiber prefabricated or custom made posts affects the 3-year survival of endodontically treated premolars. Am J Dent. 2008;21(3):179-84.

Can Say E, Kayahan B, Ozel E, Gokce K, Soyman M, Bayirli G. Clinical evaluation of posterior composite restorations in endodontically treated teeth. J Contemp Dent Pract. 2006;1;7(2):17-25.

Chrepa V, Konstantinidis I, Kotsakis GA, Mitsias ME. The survival of indirect composite resin onlays for the restoration of root filled teeth: a retrospective medium-term study. Int Endod J. 2014;47(10):967-73.

Creugers NH, Mentink AG, Fokkinga WA, Kreulen CM. 5-year follow-up of a prospective clinical study on various types of core restorations. Int J Prosthodont. 2005a;18(1):34-9.

Creugers NH, Kreulen CM, Fokkinga WA, Mentink AG. A 5-year prospective clinical study on core restorations without covering crowns. Int J Prosthodont. 2005b;18(1):40-1.

Dammaschke T, Nykiel K, Sagheri D, Schäfer E. Influence of coronal restorations on the fracture resistance of root canal-treated premolar and molar teeth: a retrospective study. Aust Endod J. 2013;39(2):48-56.

De Backer H, Van Maele G, De Moor N, Van den Berghe L. An up to 20-year retrospective study of 4-unit fixed dental prostheses for the replacement of 2 missing adjacent teeth. Int J Prosthodont. 2008;21(3):259-66.

Deliperi S, Bardwell DN. Reconstruction of nonvital teeth using direct fiber-reinforced composite resin: a pilot clinical study. J Adhes Dent. 2009;11(1):71-8.

DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials.

1986;7(3):177–88.

Ellner S, Bergendal T, Bergman B. Four post-and-core combinations as abutments for fixed single crowns: a prospective up to 10-year study. Int J Prosthodont. 2003;16(3):249-54.

Fedorowicz Z, Carter B, de Souza RF, Chaves CA, Nasser M, Sequeira-Byron P. Single crowns versus conventional fillings for the restoration of root filled teeth. Cochrane Database Syst Rev. 2012;16;5:CD009109.

Ferrari M, Vichi A, Mannocci F, Mason PN. Retrospective study of the clinical performance of fiber posts. Am J Dent. 2000a;13(Spec No):9B-13B.

Ferrari M, Vichi A, García-Godoy F. Clinical evaluation of fiber-reinforced epoxy resin posts and cast post and cores. Am J Dent. 2000b;13(Spec No):15B-18B.

Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C. Post placement affects survival of endodontically treated premolars. J Dent Res. 2007;86(8):729-34.

Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, Polimeni A, Goracci C. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res. 2012;91(7 Suppl):72S-78S.

Figueiredo FE, Martins-Filho PR, Faria-E-Silva AL. Do Metal Post-retained Restorations Result in More Root Fractures than Fiber Post-retained Restorations? A Systematic Review and Meta-analysis. J Endod. 2015;41(3):309-16.

Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent. 2007;35(10):778-86.

Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Composite resin core-crown reconstructions: an up to 17-year follow-up of a controlled clinical trial. Int J Prosthodont. 2008;21(2):109-15.

Fredriksson M, Astbäck J, Pamenius M, Arvidson K. A retrospective study of 236 patients with teeth restored by carbon fiber-reinforced epoxy resin posts. J Prosthet Dent. 1998;80(2):151-7.

Gbadebo OS, Ajayi DM, Oyekunle OO, Shaba PO. Randomized clinical study comparing metallic and glass fiber post in restoration of endodontically treated teeth.

Indian J Dent Res. 2014;25(1):58-63.

Ghavamnasiri M, Maleknejad F, Ameri H, Moghaddas MJ, Farzaneh F, Chasteen JE. A retrospective clinical evaluation of success rate in endodontic-treated premolars restored with composite resin and fiber reinforced composite posts. J Conserv Dent. 2011;14(4):378-82.

Glazer B. Restoration of endodontically treated teeth with carbon fibre posts--a prospective study. J Can Dent Assoc. 2000;66(11):613-8.

Gómez-Polo M, Llidó B, Rivero A, Del Río J, Celemín A. A 10-year retrospective study of the survival rate of teeth restored with metal prefabricated posts versus cast metal posts and cores. J Dent. 2010;38(11):916-20.

Goodacre CJ. Carbon fiber posts may have fewer failures than metal posts. J Evid Based Dent Pract. 2010;10(1):32-4.

Grandini S, Goracci C, Tay FR, Grandini R, Ferrari M. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically treated teeth. Int J Prosthodont. 2005;18(5):399-404.

Hansen EK, Asmussen E, Christiansen NC. In vivo fractures of endodontically treated posterior teeth restored with amalgam. Endod Dent Traumatol. 1990a;6(2):49-55.

Hansen EK, Asmussen E. In vivo fractures of endodontically treated posterior teeth restored with enamel-bonded resin. Endod Dent Traumatol. 1990b;6(5):218-25.

Hatzikyriakos AH, Reisis GI, Tsingos N. A 3-year postoperative clinical evaluation of posts and cores beneath existing crowns. J Prosthet Dent. 1992;67(4):454-8.

Hedlund SO, Johansson NG, Sjögren G. A retrospective study of pre-fabricated carbon fibre root canal posts. J Oral Rehabil. 2003;30(10):1036-40.

Heydecke G, Peters MC. The restoration of endodontically treated, single-rooted teeth with cast or direct posts and cores: a systematic review. J Prosthet Dent. 2002;87(4):380-6.

Hikasa T, Matsuka Y, Mine A, Minakuchi H, Hara ES, Van Meerbeek B, Yatani H, Kuboki T. A 15-year clinical comparative study of the cumulative survival rate of cast metal core and resin core restorations luted with adhesive resin cement. Int J Prosthodont. 2010;23(5):397-405.

Jongsma LA, Kleverlaan CJ, Feilzer AJ. Clinical success and survival of indirect resin composite crowns: results of a 3-year prospective study. Dent Mater. 2012;28(9):952-60.

Juloski J, Fadda GM, Monticelli F, Fajó-Pascual M, Goracci C, Ferrari M. Four-year Survival of Endodontically Treated Premolars Restored with Fiber Posts. J Dent Res. 2014;93(7 Suppl):52S-58S.

Jung RE, Kalkstein O, Sailer I, Roos M, Hämmerle CH. A comparison of composite post buildups and cast gold post-and-core buildups for the restoration of nonvital teeth after 5 to 10 years. Int J Prosthodont. 2007;20(1):63-9.

King PA, Setchell DJ, Rees JS. Clinical evaluation of a carbon fibre reinforced carbon endodontic post. J Oral Rehabil. 2003;30(8):785-9.

Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. Oper Dent. 1981;6(1):2–5

Lynch CD, Burke FM, Ní Ríordáin R, Hannigan A. The influence of coronal restoration type on the survival of endodontically treated teeth. Eur J Prosthodont Restor Dent. 2004;12(4):171-6.

Malferrari S, Monaco C, Scotti R. Clinical evaluation of teeth restored with quartz fiber-reinforced epoxy resin posts. Int J Prosthodont. 2003;16(1):39-44.

Mancebo JC, Jiménez-Castellanos E, Cañadas D. Effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts: a 3-year clinical study. Am J Dent. 2010;23(6):351-6.

Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent. 2002;88(3):297-301.

Mannocci F, Qualtrough AJ, Worthington HV, Watson TF, Pitt Ford TR. Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: five-year results. Oper Dent. 2005;30(1):9-15.

Memarpour M, Shafiei F. Restoration of primary anterior teeth using intracanal polyethylene fibers and composite: an in vivo study. J Adhes Dent. 2013;15(1):85-91.

Mentink AG, Meeuwissen R, Käyser AF, Mulder J. Survival rate and failure characteristics of the all metal post and core restoration. J Oral Rehabil. 1993a;20(5):455-61.

Mentink AG, Creugers NH, Meeuwissen R, Leempoel PJ, Käyser AF. Clinical performance of different post and core systems--results of a pilot study. J Oral Rehabil. 1993b;20(6):577-84.

Monticelli F, Grandini S, Goracci C, Ferrari M. Clinical behavior of translucent-fiber posts: a 2-year prospective study. Int J Prosthodont. 2003;16(6):593-6.

Murgueitio R, Bernal G. Three-year clinical follow-up of posterior teeth restored with leucite-reinforced ips empress onlays and partial veneer crowns. J Prosthodont. 2012;21(5):340-5.

Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. J Prosthet Dent 2005;93(2):164–70.

Näpänkangas R, Salonen MA, Raustia AM. Influence of previous restoration of the tooth on prognosis of crowns with dowels. J Oral Rehabil. 2000;27(12):1042-6.

Naumann M, Blankenstein F, Dietrich T. Survival of glass fibre reinforced composite post restorations after 2 years-an observational clinical study. J Dent. 2005;33(4):305-12.

Naumann M, Sterzenbac G, Alexandra F, Dietrich T. Randomized controlled clinical pilot trial of titanium vs. glass fiber prefabricated posts: preliminary results after up to 3 years. Int J Prosthodont. 2007;20(5):499-503.

Naumann M, Koelpin M, Beuer F, Meyer-Lueckel H. 10-year survival evaluation for glass-fiber-supported postendodontic restoration: a prospective observational clinical study. J Endod. 2012;38(4):432-5.

Patel S, Barnes JJ. The Principles of Endodontics. 2013. Oxford: Oxford University Press ISBN 9780199657513.

Paul SJ, Werder P. Clinical success of zirconium oxide posts with resin composite or glass-ceramic cores in endodontically treated teeth: a 4-year retrospective study. Int J Prosthodont. 2004;17(5):524-8.

Piovesan EM, Demarco FF, Cenci MS, Pereira-Cenci T. Survival rates of endodontically treated teeth restored with fiber-reinforced custom posts and cores: a 97-month study. Int J Prosthodont. 2007;20(6):633-9.

Ploumaki A, Bilkhair A, Tuna T, Stampf S, Strub JR. Success rates of prosthetic restorations on endodontically treated teeth; a systematic review after 6 years. J Oral Rehabil. 2013;40(8):618-30.

Preethi G, Kala M. Clinical evaluation of carbon fiber reinforced carbon endodontic post, glass fiber reinforced post with cast post and core: A one year comparative clinical study. J Conserv Dent. 2008;11(4):162-7.

Salvi GE, Siegrist Guldener BE, Amstad T, Joss A, Lang NP. Clinical evaluation of root filled teeth restored with or without post-and-core systems in a specialist practice setting. Int Endod J. 2007;40(3):209-15.

Sarkis-Onofre R, Jacinto Rde C, Boscato N, Cenci MS, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. J Dent. 2014;42(5):582-7.

Schmitter M, Rammelsberg P, Gabbert O, Ohlmann B. Influence of clinical baseline findings on the survival of 2 post systems: a randomized clinical trial. Int J Prosthodont. 2007;20(2):173-8.

Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod. 2004;30:289–301.

Segerström S, Astbäck J, Ekstrand KD. A retrospective long term study of teeth restored with prefabricated carbon fiber reinforced epoxy resin posts. Swed Dent J. 2006;30(1):1-8.

Sequeira-Byron P, Fedorowicz Z, Carter B, Nasser M, Alrowaili EF. Single crowns versus conventional fillings for the restoration of root-filled teeth. Cochrane Database Syst Rev. 2015;25;9:CD009109.

Shafiei F, Memarpour M, Doozandeh M. Three-year clinical evaluation of cuspal coverage with combined composite-amalgam in endodontically-treated maxillary premolars. Oper Dent. 2010;35(6):599-604.

Signore A, Benedicenti S, Kaitsas V, Barone M, Angiero F, Ravera G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. J Dent. 2009;37(2):115-21.

Signore A, Kaitsas V, Ravera G, Angiero F, Benedicenti S. Clinical evaluation of an oval-shaped prefabricated glass fiber post in endodontically treated premolars presenting an oval root canal cross-section: a retrospective cohort study. Int J Prosthodont. 2011;24(3):255-63.

Sjögren G, Lantto R, Tillberg A. Clinical evaluation of all-ceramic crowns (Dicor) in general practice. J Prosthet Dent. 1999;81(3):277-84.

Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. A practice-based study on the survival of restored endodontically treated teeth. J Endod. 2013;39(11):1335-40.

Skupien JA, Kreulen C, Opdam N, Bronkhorst E, Pereira-Cenci T, Huysmans MC. Effect of Remaining Cavity Wall, Cervical Dentin, and Post on Fracture Resistance of Endodontically Treated, Composite Restored Premolars. Int J Prosthodont. 2016;29(2):154-6.

Stavropoulou AF, Koidis PT. A systematic review of single crowns on endodontically treated teeth. J Dent. 2007;35(10):761-7.

Sterzenbach G, Franke A, Naumann M. Rigid versus flexible dentine-like endodontic posts--clinical testing of a biomechanical concept: seven-year results of a randomized controlled clinical pilot trial on endodontically treated abutment teeth with severe hard tissue loss. J Endod. 2012;38(12):1557-63.

Torbjörner A, Karlsson S, Odman PA. Survival rate and failure characteristics for two post designs. J Prosthet Dent. 1995;73(5):439-44.

van Dijken JW, Hasselrot L, Ormin A, Olofsson AL. Restorations with extensive dentin/enamel-bonded ceramic coverage. A 5-year follow-up. Eur J Oral Sci. 2001;109(4):222-9.

van Oirschot BA, Bronkhorst EM, van den Beucken JJ, Meijer GJ, Jansen JA, Junker R. Long-term survival of calcium phosphate-coated dental implants: a meta-analytical approach to the clinical literature. Clin Oral Implants Res. 2013;24(4):355-62.

Walton TR. A 10-year longitudinal study of fixed prosthodontics: clinical characteristics and outcome of single-unit metal-ceramic crowns. Int J Prosthodont. 1999;12(6):519-26.

Yang A, Lamichhane A, Xu C. Remaining coronal dentin and risk of fiber-reinforced composite post-core restoration failure: a meta-analysis. Int J Prosthodont. 2015 28(3):258-64.

Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. Int J Prosthodont. 2015 28(5):475-83.

Zicari F, Van Meerbeek B, Debels E, Lesaffre E, Naert I. An up to 3-Year Controlled Clinical Trial Comparing the Outcome of Glass Fiber Posts and Composite Cores with Gold Alloy-Based Posts and Cores for the Restoration of Endodontically Treated Teeth. Int J Prosthodont. 2011;24(4):363-72.

Chapter 3

A practice-based study on the survival of restored endodontically treated teeth

This chapter has been published as:

Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. A practice-based study on the survival of restored endodontically treated teeth. J Endod. 2013;39(11):1335-40.

Abstract

Introduction: This retrospective study evaluated the survival of endodontically treated teeth (ETT) and investigated factors influencing restoration and tooth survival. Methods: Data from 795 ETT were recorded, and success (restoration still intact) and survival (restoration intact or failed/repaired/replaced and tooth still in situ) were analyzed using Kaplan-Meier statistics. A multivariate Cox regression analysis was performed to assess the variables influencing success and survival. Results: At the end of the observation period (mean observation time = 4.48 years), 45 teeth had been extracted (annual failure rate for survival = 1.9% at 9.6 years) and 114 restorations had received a restorative follow-up treatment (annual failure rate for success = 4.9% at 9.6 years). Conclusions: ETT showed accept- able survival and success in the long-term. Variables showing significant influence on survival were the number of teeth in the dentition and the presence of decay at the moment the patient entered the practice.

Introduction

A traditional restorative concept for endodontically treated teeth (ETT) is to place a post in the root canal if required for retention of the restoration, especially when a large defect is present (1,2). A coronal restoration is indicated if a significant portion of the tooth's clinical crown is missing. In contemporary practice, a bonded composite is often favored rather than a full crown or amalgam restoration because a composite resin restoration may prevent tooth fracture in combination with being minimally invasive (3). However, the traditional approach is still to make a post and core and, subsequently, a crown after endondontic treatment. The necessity to place a crown on an endodontically treated tooth has been investigated in clinical trials with limited observation time, but a recent Cochrane review on this subject was inconclusive because of a lack of suitable studies (4). The optimal design to compare the longevity of different types of restorations is a prospective randomized controlled trial (5). However, because differences between groups often appear only after long-term functioning, observation times of 5 to 10 years may be necessary (3). Prospective studies with longer observation times are scarce because they are difficult to perform because of high costs, changes in materials, and a low patient recall rate after longer periods of time. Clinical trials on the outcome of restored ETT reported 0%–5% annual failure rates (AFRs), but these were based on follow-up times of only 3–5 years (6–9). Especially for ETTs with a large restoration that is often not easy replaceable, the long- term survival of restoration and survival of the tooth are important factors because complications like failing endodontic treatments and vertical root fractures may occur and result in tooth loss. ETT are usually restored with complex and extensive restorations in which repair or replacement are not easily performed, thus making long-term follow-up even more essential. Moreover, because the failure of such extensive restorations is more likely to lead to tooth loss, this should be included as an important treatment outcome.

Practice-based studies differ in methodology and techniques (10), but all offer the advantage of reflecting what can be achieved in clinical practice. When sufficient data from patient files can be collected, an analysis of factors contributing to longevity is possible. For ETT, several clinical studies are available on longevity (11–14). However, data generated in general practices reflecting routine dental care procedures are scarce. The present study aimed to evaluate the long-term longevity of ETT in a general practice environment including several restorative concepts. Several tooth- and patient-related variables were related to restoration and tooth survival.

Materials and Methods

For this retrospective study, patient files from a private practice in Germany (RW) were used from 2000–2011. Data were collected without reference to patient names (anonymously). Because of the retrospective data collection, this study was a nonintervention clinical trial without the need for local review board approval according to European guidelines for good clinical practice (CPMP/ICH/135/95).
Records from patients who regularly visited the practice were searched for the presence of ETT. Inclusion criteria for the ETT were as follows:

1. A restoration was placed at least 6 months before the last recall visit.
2. A restoration was placed within 6 months after endodontic treatment.
3. Records contained information on the ETT and the dentition (see later).

Screening of the patient files yielded 1,542 ETT, and from these, 795 ETT met the inclusion criteria. The following data were collected from the patient records:

1. Characteristics of the involved tooth and the dentition including the type of tooth, number of teeth, presence of caries at the time of entering the practice, decayed/missing/filled teeth at the moment of endodontic treatment, restorative status of ETT before endodontic treatment, and date of the first visit
2. The date of endodontic treatment including relevant information (the number of sessions, number of canals, and number of filled canals)
3. The date of placement of the follow-up restoration including relevant information such as the type of restoration, number of surfaces, placement of a post, and core buildup
4. The type and date of all interventions on the ETT in the period after endodontic treatment

The date of the last check-up visit of the patient was recorded because this was the censoring date for restorations still in place without intervention.

All endodontic treatments and restorations (inlays, crowns, telescopic crowns, and composite resin restorations) for the ETT were placed by 1 operator (RW). In case an existing crown was left in place, with the access opening restored with a composite repair restoration, the restoration was defined as an ‘‘old crown.’’ The decision regarding the indicated restoration was made by an informed consensus between the dentist and the patient.

From the files, the date and the type of all interventions were recorded for each included tooth in the period after the first restoration was placed. If no intervention was done, tooth and restoration were both considered to have successfully survived (defined as success). If the restoration was repaired or replaced, the restoration was considered to have failed, whereas the tooth was considered to have survived (defined as survival). If the tooth was extracted, both the tooth and restoration were considered to have failed.

Statistical analyses were performed using SPSS 19 (SPSS Inc, Chicago, IL) and R version 2.8.0 (Foundation for Statistical Computing, Vienna, Austria). The longevity of restorations and teeth was analyzed using Kaplan-Meier statistics and log-rank tests for differences between groups ($P < .05$). The annual failure rates were calculated from life tables. A multivariate backward stepwise Cox regression with clustering for patients was performed to analyze the influence of variables at a significance level of $P = .05$.

Results

In this study, 458 patients (230 women and 228 men, mean age = 40.5 years [standard deviation = 13.8 years]) having 795 restored ETT were included. Characteristics of patients and teeth are shown in Table 1.

TABLE 1. Characteristics of Patients and the Involved Teeth

Patient characteristics		Mean (SD)
Years in practice		5.86 (3.36) years
Number of teeth in dentition at the first visit		26.10 (5.64) teeth
Decayed teeth at the first visit		1.31 (2.27) teeth

	Number (%)		
Characteristics of ETTs	**Upper jaw**		**Lower jaw**
Type of tooth			
Total	468 (58.9)		327 (41.1)
Anterior teeth	129 (27.6)		34 (10.4)
Premolars	158 (33.8)		97 (29.7)
Molars	181 (38.7)		196 (59.9)
Type of restoration after endodontic treatment			
Old crowns		42 (5.3)	
Composite restoration		376 (47.3)	
New crowns		238 (29.9)	
Inlays		69 (8.7)	
Telescope crowns		70 (8.8)	
Post		*n* (%)	
No		686 (86.3)	
Yes		109 (13.7)	
Number of sessions for endodontic treatment		*n* (%)	
1 session		332 (41.8)	
2 sessions		326 (41)	
3 sessions		84 (10.6)	
4 sessions		34 (4.3)	
≥5 sessions		19 (2.4)	
ETT = last tooth in the arch		*n* (%)	
No		557 (70.1)	
Yes		238 (29.9)	
Number of adjacent teeth		*n* (%)	
0 (none)		46 (5.8)	
1 tooth		213 (26.8)	
2 teeth		536 (67.4)	

ETT, endodontically treated tooth.

Kaplan-Meier Survival Graphs and Log-rank Tests

During the observation time (mean = 4.48 years), 681 restored teeth were considered as successful because no intervention was needed (33 old crowns, 330 composite resin restorations, 209 new crowns, 58 porcelain inlays, and 51 telescopic crowns). One hundred fourteen teeth needed intervention on a restoration level but were still functioning and defined as ‘‘survived.’’ Forty-five teeth required extraction and were considered as failed (6 old crowns, 9 composites, 16 new crowns, 2 inlays, and 12 telescopic crowns). The survival curves and AFRs for success and survival of all teeth are shown in Figure 1A.

Figure 1B shows the success curves for the different types of restorations (log-rank test, $P < .001$). It was not feasible to calculate the AFR for old crowns, inlays, and telescopic crowns because of the small number of restorations left after the last event (repair or extraction). Between new crowns and composite resin restorations, there was no difference regarding the success of the restoration (log-rank test, $P = .545$, Fig. 1C), but for survival of the tooth, composite resin restored teeth were superior to new crowns (log-rank test, $P = .02$, Fig. 1D).

The ‘‘last tooth in the arch’’ and the ‘‘number of adjacent teeth’’ presented a significant difference for the survival of ETT (log-rank test, $P < .001$), but obviously these variables are related. Figure 1E presents the graph for ETT that were the last tooth in the arch and ETT that were not the last tooth. The success of the restoration was significantly reduced when a post was present (log-rank test, $P = .01$, Fig. 1F).

Cox Regression Analysis

Because of the numerous variables collected for teeth and dentition, several models were created randomly, meaning all the variables were tested in more than 1 model. During the analysis, only variables presenting a significant difference in 1 of the models were allocated to the final model. Thus, variables like the number of root canals, decayed/missing/filled teeth, number of check-ups, and others were excluded from Cox regression analysis.

Table 2 shows the results for Cox regression analysis. The first step of the regression including all variables (initial model) and the last step including only statistically relevant variables are presented. The factor ‘‘last tooth in the row’’ resulted in an almost 3 times higher risk ($P = .002$) for tooth failure. An increasing number of teeth and a higher number of decayed teeth in the dentition at the start of the patient observation time were favorable factors ($P < .001$) for tooth survival. The same variables that were favorable for tooth survival increased the success of the restoration. Additionally, the tooth type also had significance because anterior and premolar teeth had a reduced risk for restoration failure compared with molar teeth. The effect of the presence of a post did not reach the level of significance. The reference categories for the number of adjacent teeth, type of tooth, and type of restoration were tooth, molar, and composite, respectively.

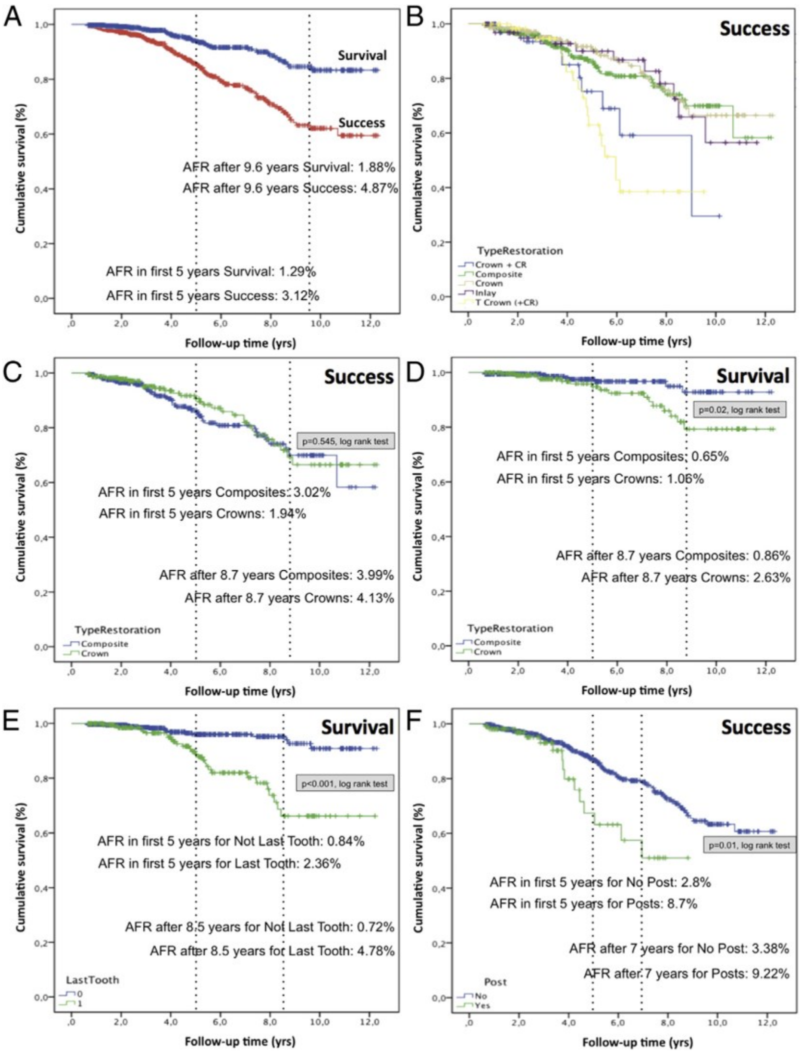

Figure 1. Kaplan-Meier graphs showing (*A*) the survival of the teeth and the success of the restoration, (*B*) the success for different types of restorations (log-rank test, $P < .001$), (*C*) the success for composites and crowns (log-rank test, $P = .545$); (*D*) survival for composites and crowns (log-rank test, $P = .02$), (*E*) survival for the last tooth in the arch versus others (log-rank test, $P < .001$), and (*F*) the success of restorations with or without a post (log-rank test, $P = .01$).

Discussion

In the present study, a retrospective survival analysis of restored ETT in a German general dental practice was made. The outcome shows that when a complete, accurate, and extensive dataset is present and a sufficient number of patients are visiting the practice on a regular basis, such an analysis can be made.

TABLE 2. Cox Regression Analysis for the Survival of ETTs and the Success of Restoration

	Survival of tooth		Success of restoration	
Variable	*P* value (95% confidence interval)	Hazard ratio	*P* value (95% confidence interval)	Hazard ratio
First step				
Age	.954 (0.97–1.03)	1	.913 (0.98–1.01)	0.99
Male	.537 (0.44–1.53)	0.82	.724 (0.64–1.37)	0.93
Last tooth in the arch	.219 (0.69–4.87)	1.84	.569 (0.65–2.12)	1.17
Post	.284 (0.14–1.79)	0.49	.037 (1.05–3.99)	2.04
Number of adjacent teeth	.758		.590	
0 adjacent teeth	1	1	1	1
1 adjacent tooth	.662 (0.46–3.32)	1.24	.282 (0.72–3.07)	1.48
2 adjacent teeth	.894 (0.24–3.48)	0.91	.414 (0.60–3.42)	1.43
Type of tooth	.950		.819	
Molar	1	1	1	1
Anterior tooth	.797 (0.30–2.51)	0.87	.034 (0.24–0.94)	0.47
Premolar	.761 (0.37–2.07)	0.87	.064 (0.37–1.03)	0.61
Number of endodontic sessions	.264 (0.88–1.61)	1.19	.100 (0.97–1.43)	1.18
Years in practice	.115 (0.77–1.03)	0.89	.191 (0.84–1.03)	0.93
Number of teeth in dentition	.017 (0.85–0.98)	0.91	<.001 (0.87–0.95)	0.91
Upper jaw	.522 (0.42–1.55)	0.81	.793 (0.64–1.39)	0.95
Decayed teeth	.033 (0.67–0.98)	0.81	.004 (0.80–0.96)	0.87
Type of restoration	.272		.369	
Composite	1	1	1	1
Old crowns	.065 (0.93–10.63)	3.14	.544 (0.55–3.07)	1.30
New crowns	.211 (0.72–4.27)	1.76	.115 (0.59–2.14)	0.67
Inlays	.720 (0.15–3.67)	0.75	.724 (0.59–2.14)	1.12
Telescope crowns	.109 (0.81–8.02)	2.55	.848 (0.42–2.02)	0.92
Last step				
Last tooth in the arch	0.002 [1.46-5.50]	2.84	*	
Post	*		.078 (0.94–3.28)	1.75
Anterior tooth	*		.01 (0.25–0.82)	0.45
Premolar	*		.02 (0.38–0.92)	0.59
Number of endodontic sessions	.069 (0.98–1.61)	1.26	*	
Number of teeth in dentition	<.001 (0.87–0.94)	0.91	<.001 (0.89–0.94)	0.91
Decayed teeth	<.001 (0.67–0.90)	0.78	.005 (0.80–0.96)	0.87

ETT, endodontically treated teeth.
*Empty cells mean that for the last step those variables were not present.

The overriding limitation of such a study is the nonrandom allocation of treatments to the teeth. Because the dentist made treatment decisions together with the patient based on the specific clinical case and an informed consent procedure, differences between the outcomes of different treatments did not provide information on which technique is the best. For that purpose, randomization would be necessary, which is not an option in the setting. However, the advantage of the present study is that it reflects the situation in daily practice, and it provides information on what can be expected from certain treatments performed during routine dental care. More importantly, it offers the advantage of a larger sample size and an extended observation time because patients may revisit a prestigious and stable practice for 20 years or more (15), including a large number of restorations. This last feature offers the opportunity to analyze the dataset in a multivariate analysis, including many relevant patient, dentition, and tooth variables. Still, interpretation of the outcome should be done with care because many unknown variables may have played a role in the general practice setting.

The log-rank test as used here is of limited suitability. For instance, regarding restorations, it compares restorative groups based on the assumption that these groups are comparable in all other respects. Under this assumption, a tooth that received a crown had a significantly lower survival rate than a tooth that was restored with a direct composite resin restoration (log-rank test, P = .02). Obviously, this assumption is not valid. The practitioner confirmed that in the practice ETT were restored routinely with a direct composite and that the placement of crowns was limited to severely broken down teeth. Therefore, under these circumstances, drawing conclusions about the superiority of any restoration type based on a log-rank test is clearly inappropriate. The multivariate approach takes into account all (included) factors acting together, and an adjustment among variables is achieved, resulting in a more reliable outcome. However, the problem of different indications for restorations is not completely resolved.

Kaplan-Meier analysis including the calculation of AFRs from life tables can be considered as the best tool to express restoration longevity (10). It can be used to examine a single factor, but this is appropriate only when groups are the result of randomization or it can be argued that confounding is not a threat to the study (3). However, to verify the influence of variables on survival, a Cox regression multivariate analysis might be considered as the gold standard and log-rank tests should be applied with caution.

The main result of the present study is that in a general practice environment, it is possible to achieve good longevity for restored ETT. After 9.6 years of observation, the AFR for survival of the teeth was 1.9%, whereas for the restorations the AFR was 4.9%. Notwithstanding the extensive and often difficult clinical cases, restoration success rates are comparable with those in vital teeth studies (3,15,16), indicating that the dental work has a high-quality level, which is also shown by the extensive dataset the practitioner keeps regarding his treatments.

In the Cox regression analysis, several variables showed a significant influence. Although the number of adjacent teeth significantly affects tooth survival according to the log-rank test, this effect was not shown in the regression, mainly because it was adjusted by the ‘‘last tooth in the row,’’ which presented a 3 times higher risk of failure in the multivariate analysis and was also significant according to the log- rank test. The number of teeth in the dentition and the number of decayed teeth were found to be favorable factors for longevity. The number of teeth was already mentioned as a health indicator in other studies (17–20), and dentists should realize that severely mutilated dentitions have a worse prognosis for restorative treatment.

The protective effect of the number of decayed teeth at the start of the observation is remarkable. An explanation could be that, especially in the starting years of the practice, patients entered with a low-quality level of restorative work and were seeking a good dentist. These patients, with multiple problems because of insufficient dental restorations and untreated caries, were very motivated and as a result could be treated very successfully partially because of the successful prevention program. Another explanation may be that the initial carious teeth may have been less broken down and easier to treat with an endodontic treatment and restoration than those teeth that previously have been restored extensively, resulting in a more difficult treatment and a worse prognosis.

Restorations placed on premolars and anterior teeth were more successful compared with restorations in molars. Actually, the influence of the type of tooth is not well established in the literature. The results of our study are in accordance with Da Rosa Rodolpho et al (15), who found a higher probability of failure in molars, and Aquilino and Caplan (21), who stated that second molars had poor survival. However, the results of Naumann et al (22) showed that anterior teeth had a 2-fold increased failure rate compared with premolars or molars, and Balkenhol et al (23) concluded that the survival probability did not depend on the location of the tooth in the dental arch.

Restoring ETT is often associated with the placement of a post (7,24,25). This study showed that according to multivariate analysis the use of a post had no significant effect on either tooth survival or restoration success although after 7 years of observation a 3 times higher AFR (9.2%) for restorations placed with posts was found compared with restorations placed without a post (3.4%). It can be explained by the dentist's decision making, resulting in more teeth with a high level of coronal breakdown that received a post.

No data were collected in the present study on the quality of the endodontic treatment itself based on the radiographic information. This will be the subject of a further study.

The longevity of teeth and dental restorations is not only related to the restorative therapy choices but also to operator- and patient-related factors (26). This study shows that in the long-term some patient-/dentition-related factors had a significant influence on the outcome. No conclusions can be made about the different choices for restorative therapy more than that in the investigated practice; the dentist was able to achieve an acceptable survival for ETT, and the choices for different therapies in different situations were all successful. Two restorative choices appear to lead to an increased failure, repaired crowns and telescopic crowns, as can be seen in Figure 1B. From repaired direct restorations, it is known that an increased AFR is found compared with unrepaired restorations (27). However, a repair can be considered a minimally invasive simple restorative technique, postponing the placement of a new restoration, and as such has some advantages. A telescopic crown is only placed in severely mutilated dentitions; most of the time it functions as an abutment for removable partial denture or fixed partial denture with a worse prognosis for restorative treatment. This may explain the limited survival of these restorations, and dentists should inform their patients about this when large rehabilitations including telescopic crowns are performed. However, even with a limited prognosis, keeping the ETT functioning in the mouth is a good option. A study comparing the quality of life of patients with ETT versus implant-treated cases showed similar satisfaction in both groups, but all participants expressed the value of having their own dentition (28). The results of the present study show that restorations on ETT placed in a German dental practice showed favorable survival on restoration and tooth level.

References

1. Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent. 1994;71(6):565-7.
2. Morgano SM, Brackett SE. Foundation restorations in fixed prosthodontics: current knowledge and future needs. J Prosthet Dent. 1999;82(6):643-57.
3. Opdam NJ, Bronkhorst EM, Loomans BA, et al. 12-year survival of composite vs. amalgam restorations. J Dent Res. 2010;89(10):1063-7
4. Fedorowicz Z, Carter B, de Souza RF, et al. Single crowns versus conventional fillings for the restoration of root filled teeth. Cochrane Database Syst Rev 2012;5: CD009109.
5. American Dental Association. ADA Policy Statement on Evidence-Based Dentistry. Available at: http://www.ada.org/1754.aspx. Accessed September 11, 2010.
6. van Dijken JW, Hasselrot L, Ormin A, et al. Restorations with extensive dentin/enamel- bonded ceramic coverage. A 5-year follow-up. Eur J Oral Sci. 2001;109(4):222–9.
7. Mannocci F, Bertelli E, Sherriff M, et al. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent. 2002;88(3):297–301.
8. Zicari F, Van Meerbeek B, Debels E, et al. An up to 3-year controlled clinical trial comparing the outcome of glass fiber posts and composite cores with gold alloy- based posts and cores for the restoration of endodontically treated teeth. Int J Prosthodont. 2011;24(4):363–72.
9. Murgueitio R, Bernal G. Three-year clinical follow-up of posterior teeth restored with leucite-reinforced IPS empress onlays and partial veneer crowns. J Prosthodont. 2012;21(5):340–5.
10. Opdam NJ, Bronkhorst EM, Cenci MS, et al. Age of failed restorations: a deceptive longevity parameter. J Dent. 2011;39(3):225–30.
11. Hansen EK, Asmussen E. In vivo fractures of endodontically treated posterior teeth restored with enamel-bonded resin. Endod Dent Traumatol. 1990;6(5):218–25.

12. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. J Prosthet Dent. 2005;93(2):164–70.
13. Fokkinga WA, Kreulen CM, Bronkhorst EM, et al. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent. 2007;35(10):778–86.
14. Ferrari M, Vichi A, Fadda GM, et al. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res. 2012;91(7 Suppl):72S–8.
15. Da Rosa Rodolpho PA, Donassollo TA, Cenci MS, et al. 22-year clinical evaluation of the performance of two posterior composites with different filler characteristics. Dent Mater. 2011;27(10):955–63.
16. Opdam NJ, Bronkhorst EM, Roeters JM, et al. A retrospective clinical study on longevity of posterior composite and amalgam restorations. Dent Mater. 2007;23(1):2–8.
17. Holm-Pedersen P, Schultz-Larsen K, Christiansen N, et al. Tooth loss and subsequent disability and mortality in old age. J Am Geriatr Soc. 2008;56(3):429–35.
18. Osterberg T, Carlsson GE, Sundh V, et al. Number of teeth-a predictor of mortality in 70-year-old subjects. Community Dent Oral Epidemiol. 2008;36(3):258–68.
19. Holmlund A, Holm G, Lind L. Number of teeth as a predictor of cardiovascular mortality in a cohort of 7674 subjects followed for 12 years. J Periodontol. 2010; 81(6):870–6.
20. Savoca MR, Arcury TA, Leng X, et al. Severe tooth loss in older adults as a key indicator of compromised dietary quality. Public Health Nutr. 2010;13(4):466–74.
21. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002;87(3):256–63.
22. Naumann M, Koelpin M, Beuer F, et al. 10-year survival evaluation for glass-fiber- supported postendodontic restoration: a prospective observational clinical study. J Endod. 2012;38(4):432–5.
23. Balkenhol M, Wöstmann B, Rein C, et al. Survival time of cast post and cores: a 10- year retrospective study. J Dent. 2007;35(1):50–8.

24. Grandini S, Goracci C, Tay FR, et al. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically treated teeth. Int J Prosthodont. 2005;18(5):399–404.
25. Signore A, Benedicenti S, Kaitsas V, et al. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic crown coverage. J Dent. 2009;37(2):115–21.
26. Demarco FF, Corrêa MB, Cenci MS, et al. Longevity of posterior composite restorations: not only a matter of materials. Dent Mater. 2012;28(1):87–101.
27. Opdam NJ, Bronkhorst EM, Loomans BA, et al. Longevity of repaired restorations: a practice based study. J Dent. 2012;40(10):829–35.
28. Gatten DL, Riedy CA, Hong SK, et al. Quality of life of endodontically treated versus implant treated patients: a University-based qualitative research study. J Endod. 2011;37(7):903–9.

Chapter 4

Survival of restored endodontically treated teeth in relation to periodontal status

This chapter has been published as:

Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. Survival of restored endodontically treated teeth in relation to periodontal status. Braz Dent J. 2016;27(1):37-40.

Abstract

The aim of present study was to investigate the success and survival of restored endodontically treated teeth (ETT) in a general practice environment related to periodontal parameters. Data from 360 restored ETT treated between 2000 and 2011 were collected. Dates of interventions like restorations, repairs, replacements and extractions were recorded. Additionally, general information about patients and dentitions as well as periodontal status was recorded. Success was analyzed using Kaplan-Meier statistics and a multivariate Cox regression analysis was performed to assess variables influencing success and survival. After a mean observation time of 4.34 years (range 0.6 - 11.6 yrs), 19 teeth were extracted and 27 restorations needed repair or replacement. According to the Cox regression, increasing maximum pocket depth of the tooth resulted in a higher risk for failure ($p=0.012$). In conclusion, periodontal pocket depth was found to be a significant factor in the survival of restored endodontically treated teeth.

Introduction

Endodontic treatment has been evaluated in the scientific literature at many different levels, starting at the level of the success of the treatment itself in preventing or curing periapical lesions (1), through the level of success of restoring to function endodontically treated teeth (2), and ending at the level of long-term survival of ETT (3). Slowly but surely, it is becoming clear that factors beyond the quality of endodontic treatment may be relatively important in determining long term outcome. For instance, the quality of the coronal restoration was shown to be more important in endodontic treatment success than the quality of the endodontic filling (4). When looking at the reasons for extraction of ETT, endodontic failure represents often only a minor proportion of total failure, with non-restorable breakdown & caries (5), root fracture (6), or periodontal disease (7) being reported as the main failure reason.

Increasingly, factors at the level of the complete dentition or the complete patient are being included in studies of success and survival of ETT. In a recent study we have reported on a retrospective study in 795 teeth in 458 patients in a private practice, showing that dentition related factors, like number of teeth in the dentition and being he last tooth in the arch, may play an important role (3).

It is a commonly accepted principle in dentistry that tooth prognosis is taken into account before indicating extensive and possibly expensive treatments, such as endodontic treatment. One of the aspects often included in determining prognosis is the periodontal status of the tooth, usually in terms of attachment loss (8). The effect of endodontic treatment on the success of subsequent periodontal treatment has been studied (9). However, there is very limited scientific evidence for the effect of periodontal status on the outcome of endodontic treatment (10) and on the survival of restored ETT.

In a recent report on 1175 ETT in 411 patients, where the majority of the patients were advanced periodontal cases rehabilitated with fixed prostheses, the 10-year survival rate was high: 93% and the most common reason for extraction was recurrent periodontal disease (43%) (11). A few cross-sectional studies are available where both periodontal status and endodontic status were evaluated. One study showed slightly more attachment loss (0.6 mm) in ETT than in contralateral untreated controls (12). However, this may have been due to the ETT being restored with crown of which 75% were judged to be defective. In a more recent study evaluating 50 molar teeth restored with crowns, the occurrence of negative events, apart from extractions also including retreatments, was found to be related to attachment loss of the tooth and “prognostic value” (13).

As so little evidence is available on the effect of periodontal status on the survival of ETT, we performed an additional analysis on a subset of a retrospective study, selecting those teeth / patients for which periodontal status and treatment information was available. The aim of the present retrospective clinical study, therefore, was to investigate the success and survival of endodontically treated teeth in a general practice environment as related to periodontal parameters.

Materials and Methods

The present study is a non-intervention clinical trial without need for local review board approval according to European guidelines for good clinical practice (CPMP/ICH/135/95). A previous report describes the parent data set and the recorded variables for the current study (3). In brief: digital files from a German private practice were used for collecting data for this practice-based survival study. Inclusion criteria were patients that had received a root canal treatment and subsequent restoration (composite resin or crowns). Patients should be loyal to the practice, and ETT with a minimal observation time of 6 months were included. From the parent data set of 458 patients (795 ETT), 158 (93 female and 65 male) fulfilled the additional inclusion criterion of periodontal status and treatment data being available, corresponding to 360 ETT.

From the patient records, dates of endodontic and restorative procedures, date and type of intervention (repairs/replacement/extractions) and data for periodontal treatments or periodontal check up were collected. The last visit was considered as the censoring date for restorations and tooth still in situ. The following periodontal characteristics were collected from the patient files:

* Maximum pocket depth of tooth: Pockets were measured before endodontic treatment at six sites, and the highest value of the 6 measurements was recorded as maximum pocket depth of the tooth.
* Average of maximum pocket depth of dentition: An average of maximum pocket depths of all teeth (as described above) was calculated.

Statistical analyses were performed with SPSS 20 (SPSS Inc., Chicago IL, USA) and R (v. 3.0.2: R. Foundation for Statistical Computing, Vienna, Austria). For the outcome success, failure was defined as an ETT needing repair, a new restoration or extraction. For the outcome survival, failure was defined as an ETT being extracted. The influence of variables on success/survival was analyzed using Cox-regression with a Gamma distributed frailty term to model for the clustering of multiple ETT in one patient. As a starting point for the Cox model, the final model from the parent dataset was used (3). For this model, the best extension with additional periodontal information was evaluated. For visualization of the effect of the periodontal variable, Kaplan-Meier curves were constructed for both success and survival.

Results

The patients (mean age 44.3 years, SD 12.5) included in our study had on average 25.9 teeth in their dentition. The maximum pocket depth of the evaluated tooth ranged from 2 to 10 mm. Average maximum pocket depth of the dentition ranged from 2.5 to 6.5 mm.

After a mean observation time of 4.34 years (range 0.6 - 11.6 yrs), 19 teeth were extracted and 27 restorations needed repair or replacement. This involved 5 old crowns, 21 composites and 22 new crowns. The annual failure rates (AFR) for success of restorations and survival of teeth are not reported here as they have been more extensively reported on in the parent study (3).

Due to the reduced sample size, with reduced number of events (48 for success and 19 for survival), the Cox regression models could include a maximum of 5 and 2 factors for success and survival, respectively. Therefore, in the first model, the factor with the highest P-value was omitted (presence of a post, $p>0.1$). In the second model, combinations of variables from the original models with the periodontal variables were explored.

The addition of "maximum pocket depth of tooth treated" to the model showed to be the best extension of the starting models. Adding the average maximum pocket depth of the patient to this extended model was not a statistically significant improvement of either model. In Table 1, the best extended models are presented for both success and survival. For tooth survival, the number of teeth in the dentition functioned as a protection factor while an increasing maximum pocket depth represented a higher failure risk ($p<0.05$) (Table 1).

For a better visualization of the influence of pocket depth on success and survival of ETT, a classification was made. Three groups were created: 2 - 3mm, 4 - 5mm and > 5mm of pocket depth. Kaplan-Meier survival curves were made for these groups (Figure 1).

Table 1: Cox regression model. Extension of starting model with "Pocket depth of tooth treated"

(Last Step) Variable	p-Value	Hazard ratio	95% Confidence Interval	
			Lower	Upper
Success				
Pocket Depth Tooth	0.69	1.06	0.79	1.43
Number of Teeth in Dentition	0.004	0.92	0.87	0.97
Premolars (reference=Incisor)	0.71	0.84	0.33	2.13
Molars (reference=Incisor)	0.1	2.25	0.85	5.94
Decayed teeth	0.02	0.84	0.72	0.97
Survival				
Pocket Depth Tooth	0.012	1.60	1.11	2.30
Number of Teeth in Dentition	<0.001	0.88	0.84	0.94

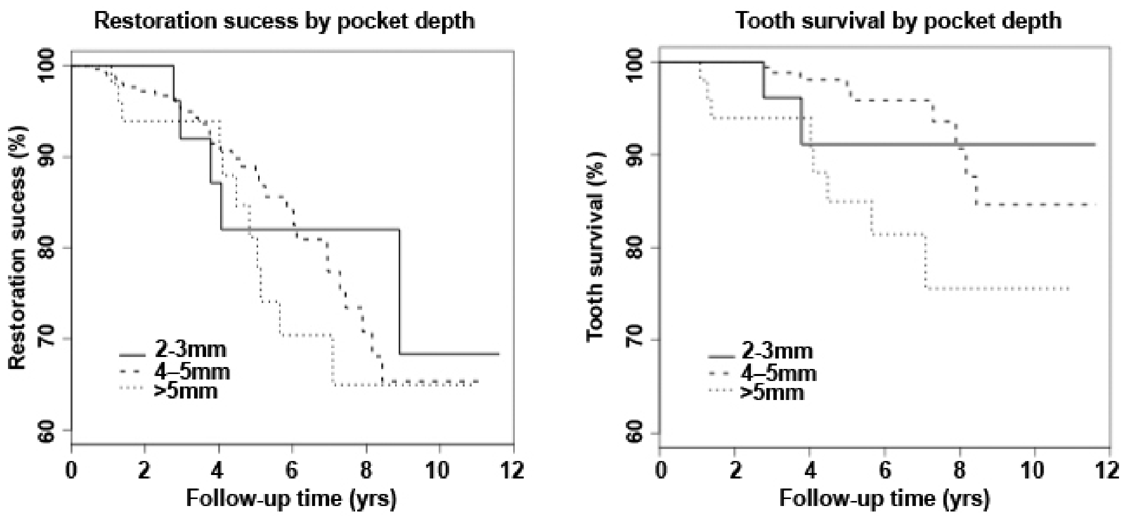

Figure 1: Kaplan-Meier for ETT success (a) and survival (b) by maximum pocket depth of the tooth

Discussion

This practice based study evaluated the survival and success of endodontically treated teeth originating from one dental practice and one operator (RW). The outcome of this kind of practice based studies has to be interpreted with care and appropriate statistics should be applied like the backward stepwise Cox regression that enables to do a multi-variate analysis, and consequently, analyze the risk factor of variables.

Of the additional periodontal variables included in this study, only maximum pocket depth of the treated tooth was found to be a significant factor in tooth survival. This is in accordance with the study of Setzer (13), where the need for retreatment or extraction was associated with pre-operative attachment loss of the tooth. The size of the effect, as may be seen by the divergence of the Kaplan-Meier curves, is substantial. The calculated hazard ratio of 1.60 indicates that every extra mm of maximum pocket depth increases the risk of failure of the restored ETT with 60%. Moreover, extra care in periodontitis patients with endodontically treated teeth must to be performed due to high probability of more bone loss when compared to untreated teeth (14).

Separately, pocket probing depth and endodontically treated teeth by itself were already demonstrated as factors that can affect tooth survival (15). However, in our study, we showed that periodontal disease in ETT could act as an extra risk factor. Overall periodontal status of the dentition as expressed by average pocket depth was not a significant factor, indicating that periodontal disease probably acts more as a tooth-related risk factor, than as a general dental health related factor. Our results confirm the importance of periodontal status of the tooth in the survival of endodontically treated teeth, outstripping more commonly reported factors such as crown or post placement.

Deeper pocket also increases the crown length, hence, increasing stress concentration, which may explain the influence on tooth survival (16). On the other hand, as also demonstrated in the previous study, a higher number of teeth in the dentition acts as a protection factor, possibly because it may be viewed as an overall dental health indicator.

In conclusion, periodontal pocket depth was found to be a significant factor in the survival of restored endodontically treated teeth.

References

1. Weiger R, Rosendahl R, Löst C. Influence of calcium hydroxide intracanal dressings on the prognosis of teeth with endodontically induced periapical lesions. Int Endod J. 2000;33(3):219-26.
2. Scotti N, Eruli C, Comba A, Paolino DS, Alovisi M, Pasqualini D, et al. Longevity of class 2 direct restorations in root-filled teeth: A retrospective clinical study. J Dent. 2015;43(5):499-505.
3. Skupien JA, Opdam N, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, et al. A practice-based study on the survival of restored endodontically treated teeth. J Endod. 2013;39(11):1335-40.
4. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J. 1995;28(1):12-8.
5. Zadik Y, Sandler V, Bechor R, Salehrabi R. Analysis of factors related to extraction of endodontically treated teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008;106(5):e31-5.
6. Landys Borén D, Jonasson P, Kvist T. Long-term survival of endodontically treated teeth at a public dental specialist clinic. J Endod. 2015;41(2):176-81.
7. Touré B, Faye B, Kane AW, Lo CM, Niang B, Boucher Y. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod. 2011;37(11):1512-5.
8. McGuire MK, Nunn ME. Prognosis versus actual outcome III The effectiveness of clinical parameters in accurately predicting tooth survival. J Periodontol. 1996;67(7):666-74.
9. Jansson L, Ehnevid H, Lindskog S, Blomlöf L. The influence of endodontic infection on progression of marginal bone loss in periodontitis. J Clin Periodontol. 1995;22(10):729-34.
10. Stassen IG, Hommez GM, De Bruyn H, De Moor RJ. The relation between apical periodontitis and root-filled teeth in patients with periodontal treatment need. Int Endod J. 2006;39(4):299-308.
11. Fonzar F, Fonzar A, Buttolo P, Worthington HV, Esposito M. The prognosis of root canal therapy: a 10-year retrospective cohort study on 411 patients with 1175 endodontically treated teeth. Eur J Oral Implantol. 2009;2(3):201-8.

12. Iqbal MK, Johansson AA, Akeel RF, Bergenholtz A, Omar R. A retrospective analysis of factors associated with the periapical status of restored, endodontically treated teeth. Int J Prosthodont. 2003;16(1):31-8.
13. Setzer FC, Boyer KR, Jeppson JR, Karabucak B, Kim S. Long-term prognosis of endodontically treated teeth: a retrospective analysis of preoperative factors in molars. J Endod. 2011;37(1):21-5.
14. Timmerman MF, Van der Weijden GA. Bone level around endodontically treated teeth in periodontitis patients. J Clin Periodontol. 2006;33(9):620-5.
15. Graetz C, Schützhold S, Plaumann A, Kahl M, Springer C, Sälzer S, et al. Prognostic factors for the loss of molars - an 18-years retrospective cohort study. J Clin Periodontol. 2015;42(10):943-50.
16. Roscoe MG, Noritomi PY, Novais VR, Soares CJ. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. J Prosthet Dent. 2013;110(2):116-6.

Chapter 5

Effect of Remaining Cavity Wall, Cervical Dentin, and Post on Fracture Resistance of Endodontically Treated, Composite Restored Premolars

This chapter has been published as:

Skupien JA, Kreulen C, Opdam N, Bronkhorst E, Pereira-Cenci T, Huysmans MC. Effect of Remaining Cavity Wall, Cervical Dentin, and Post on Fracture Resistance of Endodontically Treated, Composite Restored Premolars. Int J Prosthodont. 2016;29(2):154-6.

Abstract

Purpose: The aim of this study was to examine the effect of remaining buccal cavity wall, remaining cervical tissue, and post on the fracture strength of endodontically treated restored premolars. Materials and Methods: Teeth were randomly allocated to 10 experimental groups (n = 10) according to cavity design and presence or absence of post or to a control group. After thermal and mechanical aging, ramped loading until fracture was performed. Results: A high cervical outline (417 N) and the presence of a post (189 N) increased fracture strength, but both factors together had an antagonistic effect of −218 N, resulting in a higher strength of not 606 N (417 + 189) but 388 N. The risk of catastrophic failure increased (OR = 3.17) when a post was present.

Introduction

Restoration of endodontically treated teeth (ETT) has changed dramatically since the introduction of adhesive direct restoration options, reducing the need for posts. Generally, the more tooth tissue is left, the stronger the restored tooth is, and the lower the reinforcing effect of a post (1,2). Posts may also negatively influence the fracture mode, leading to more catastrophic failure. The aim of this study was to evaluate the effects of remaining tooth structure and post placement on fracture resistance and fracture type of restored ETT.

Materials and Methods

Sound single-rooted maxillary premolars (N = 100) were selected according to root length (14 ± 1 mm) and mesiodistal (7.3 mm ± 10%) and buccolingual dimensions (9.2 mm ± 10%). A total of 20 teeth were used as sound controls. These teeth were embedded up to 2 mm below the cementoenamel junction (CEJ), followed by endodontic treatment, control groups excepted. The rest received one of four standardized preparations (Figure 1) with either a remaining buccal wall or no wall (1.5 mm width), and a high or low cervical outline (2 mm above or 1 mm below the CEJ). Half of each preparation group received a glass fiber post (Exacto, Angelus; Unicem 2, 3M ESPE), leaving 4 mm of apical seal. The composite restorations (Scotchbond Multi-Purpose + Z350; 3M ESPE) were made according to the average dimension of the control group teeth.

A combination of thermal (× 6,000, 5/55°C water baths, dwell time 10 seconds) and mechanical fatigue loading (occlusal loading in 45-degree angle toward buccal cusp, × 5,000, 100 N, 5 Hz) was performed in all groups except one control group. Subsequently, all teeth were subjected to ramped loading (in same direction as fatigue) until fracture. Fractures were classified as catastrophic/noncatastrophic (below/above the embedding level, respectively).

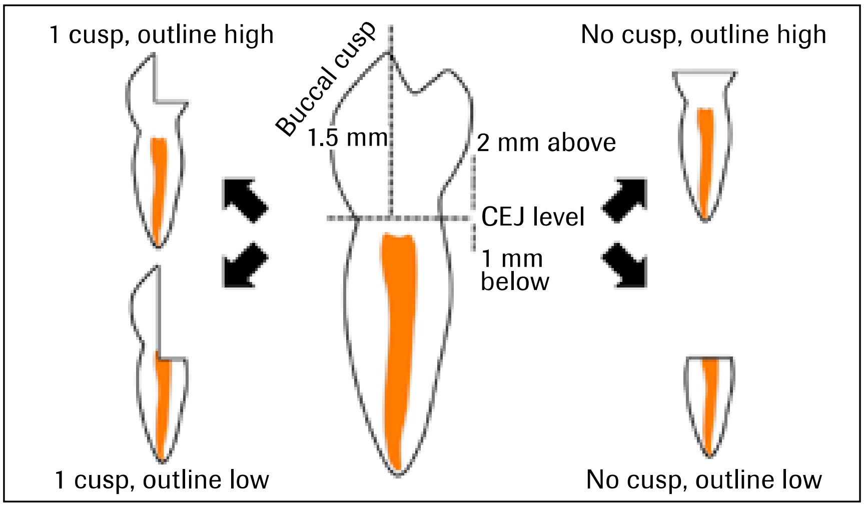

Fig 1 Basic preparation designs. Each design was used in two groups: with and without a post. CEJ = cementoenamel junction.

Fracture load results were analyzed using analysis of variance (ANOVA) (Tukey post hoc) and linear regression modeling. Fracture type was analyzed using logistic regression (all tests [$\alpha = .05$]).

Results

Table 1 shows fracture load results. Combinations with the most remaining tooth tissue (sound or high outline with remaining buccal wall) demonstrated the highest strength. Combinations with a low outline showed low fracture strengths, especially those samples without a post (*P* = .004).

Only a high cervical outline and the presence of a post significantly increased fracture strength (Table 2), with the outline effect more than twice that of applying a post (417 N compared to 189 N). However, a combination of these two factors had an antagonistic effect of 218 N, resulting in a net strength increase of only 388 N. The remaining buccal wall had no significant effect (*P* = .091).

Table 1 Fracture Loads of the Restored Premolars and Frequencies of Typical Failures

Group[1]	Mean (SD) (N)[2]	Catastrophic / non-catastrophic fracture (no.)
Sound teeth, no fatigue	1089.9 (192.8) A	5/5
1 cusp, outline high, no post	971.8 (191.7) AB	6/4
1 cusp, outline high, with post	872.3 (169.9) AB	5/5
Sound teeth, fatigued	872.1 (160.1) AB	5/5
No cusp, outline high, with post	764.5 (60.5) BC	7/3
No cusp, outline high, no post	723.4 (163.4) C	1/9
No cusp, outline low, with post	661.3 (184.6) CD	3/7
1 cusp, outline low, with post	578.2 (182.0) CD	6/4
No cusp, outline low, no post	436.2 (121.4) D	1/9
1 cusp, outline low, no post	424.0 (170.0) D	3/7

[1]Results are ordered from high to low mean fracture load.
[2]Different uppercase letters represent statistically significant group differences (ANOVA/Tukey test comparison; $P < .05$)

Table 2 Linear Regression Model, with the Three Independent Variables and the Significant Interaction Term[1]

Variable	Effect	95% confidence interval		Significance
(Constant)	397	Lower	Upper	
Cusp	65	−10	141	.091
Cervical outline	417	310	524	.000
Post	189	82	297	.001
Cervical outline and post	-218	−370	−67	.005

[1]R-square = 0.519)
Values of the variables in the model:
Cusp: no = 0, yes = 1
Cervical outline: low = 0, high = 1
Post: no = 0, yes = 1

A post significantly increased the risk of catastrophic failure (OR = 3.17; P = .02), with remaining buccal wall and outline level showing no significant effect on the type of failure (Table 3). The higher risk of catastrophic failure when a post is placed in a situation with a high outline level was most apparent when the buccal wall was absent (Table 1).

Table 3 Logistic Regression Model with the Three Determinants of Failure

Variable	Odds ratio	95% confidence interval		Significance
Constant	.15	Lower	Upper	
Cusp	2.55	0.96	6.74	.059
Cervical outline	2.03	0.77	5.35	.150
Post	3.17	1.19	8.40	.020

Discussion

Preservation of tooth structure at the cervical area increased tooth strength, which confirms the findings of earlier studies (3,4). Higher strength was expected when the buccal wall remained; however, that effect was relatively small and not significant. Although the presence of a buccal wall seemed to have greater strengthening effect when the outline was high, which could be explained by the better support in those situations, this difference was only significant when no post was used. This study also showed a positive effect of post placement on tooth strength. However, this effect could not compensate for the loss of strength due to a low outline. Moreover, the post lost its strengthening effect with more remaining tooth tissue. An opposite result was reported earlier (4), but in that study a covering nonadhesive crown was used.

Both tooth tissue reducing factors and post placement showed a higher risk of catastrophic failures. However, the only statistically significant factor was post placement. Although a previous study also reported no significant strengthening effect of fiber posts, that study reported mostly reparable failures with posts (5). This discrepancy may be related to the lack of fatigue loading or the direction of static loading.

Conclusion

The presence of cervical dentin and, to a lesser degree, a fiber post increased fracture resistance of composite restored ETT. However, the post increased the risk of catastrophic failure, especially in the presence of a remaining cavity wall.

References

1. Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of ferrule and post placement on fracture resistance of endodontically treated teeth after fatigue loading. J Dent. 2013;41(3):207–15.
2. Mancebo JC, Jiménez-Castellanos E, Cañadas D. Effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts: A 3-year clinical study. Am J Dent. 2010;23(6):351–6.
3. Ferrari M, Cagidiaco MC, Grandini S, De Sanctis M, Goracci C. Post placement affects survival of endodontically treated premolars. J Dent Res. 2007;86(8):729–34.
4. Mangold JT, Kern M. Influence of glass-fiber posts on the fracture resistance and failure pattern of endodontically treated premolars with varying substance loss: An in vitro study. J Prosthet Dent. 2011;105(6):387–93.
5. Sorrentino R, Monticelli F, Goracci C, et al. Effect of post-retained composite restorations and amount of coronal residual structure on the fracture resistance of endodontically treated teeth. Am J Dent. 2007;20(4):269–74.

Chapter 6

Crown vs. Composite for Post-retained Restorations: a Randomized Clinical Trial

This chapter has been published as:

Skupien JA, Cenci MS, Opdam N, Kreulen C, Huysmans MC, Pereira-Cenci T. Crown vs. Composite for Post-retained Restorations: a Randomized Clinical Trial. J Dent. 2016;48:34-9.

Abstract

Objectives: This randomized clinical trial compared the survival of composite resin restorations and metal-ceramic crowns on endodontically treated teeth that received a glass fiber post using 2 different cementation methods. Methods: Forty-seven patients (age 42.5±11.5) with fifty-seven endodontically treated teeth with extensive coronal damage but always with one intact surface were randomly allocated according to the type of coronal restoration: metal-ceramic crown or composite resin. In case of crown restoration, a core buildup was performed with microhybrid composite resin. The dentin bonding agent and composite resin used were the same for both direct and indirect restorations. Descriptive analysis was performed using FDI clinical criteria and survival of restorations/teeth analyzed using Kaplan-Meier statistics and log-rank tests. Results: 57 restorations (30 composite resin and 27 crowns) were made in 47 patients. The recall rate was 100% and follow up time ranged between 1 and 5 years. One tooth was extracted 11 months post-restoration due to root fracture (composite group). Eight composite restorations and one crown had reparable failures, all due to secondary caries or restoration fracture. The overall annual failure rate (AFR) was 0.92% after 50 months for success of the restorations, with 1.83% for the composite group and 0.26% for the metal-ceramic crown group. The log-rank test showed no difference for survival according to the type of restoration ($p=0.344$). However, for success rates, metal-ceramic crowns demonstrated better performance ($p=0.022$). Conclusions: Indirect restorations provided higher acceptable clinical performance and lower need for re-intervention, but both types of restorations presented good survival rates. (NCT01461239)

Introduction

The restorative clinical success of endodontically treated teeth is influenced by the use of posts (1,2), the type of the coronal restoration (3,4) or its design (1,2,5). Even different strategies of using similar materials influence restoration survival (6-8). Understanding the limitations and advantages of materials and techniques may act as a guideline for clinicians in restoring endodontically treated teeth.

Based on a minimally invasive concept, where pre-fabricated glass fiber posts in combination with a resin composite core restoration preserve sound dental structure, the risk of root fracture may be reduced and the retention of restorations enhanced (9,10). The last step in this process is the choice of type of final restoration. Although a covering crown could be considered the standard reconstruction of a severely compromised tooth (11), numerous studies reported good results for large direct composite resin restorations in vital teeth (12-14). Advantages of direct restorations are lower cost, preservation of sound dental tissue, short chair time and greater options for repair, if necessary.

Although direct composite restorations and (metal and/or ceramic) crowns are very different approaches, there is very little evidence to guide the clinician in their choice of restoration in endodontically treated teeth. For teeth with sufficient ferrule, composite resins as well as metal-ceramic crowns were reported to have high survival rates (3,7,15). However, the choice for either restoration is guided by clinical success factors like the amount of remaining tooth material. Therefore, comparing the performance of different restoration types by combining different studies using various clinical configurations is not informative (16,17).

Thus, the aim of this study was to compare in a randomized clinical trial the survival of composite resin restorations and metal-ceramic crowns used to restore endodontically treated teeth.

Materials and Methods

Experimental Design

The present study is registered at ClinicalTrials.gov (NCT01461239) and was a parallel group randomized controlled clinical trial. The study was approved by the Research and Ethics Committee (Protocol 122/2009) of the Federal University of Pelotas, and described according to the CONSORT recommendations and based on an assumption of equivalence of treatments.

Teeth were restored with a glass fiber post cemented with regular or self-adhesive resin cement, composite core and a direct or indirect restoration, according to the randomization process. Patients were recalled up to 60 months for clinical and radiographic examination. Survival curves were created and the type of failure was evaluated.

Sample Size Calculation

Sample size calculation was based on the fact that previously published papers with similar design showed no differences between direct and indirect restorations for endodontically treated teeth (3,18-22). In that sense, if there is truly no difference between the standard (crown) and experimental treatment (direct composite resin), and considering that the average tooth survival rate after 5 years would be of 96%, 30 teeth per group would be required to be 90% sure that the limits of a two-sided 90% confidence interval will exclude a difference between the standard and experimental group of more than 18% (considered to be a clinically significant threshold), based on the equivalence of the treatments, and taking into account a possible 20% patient loss.

Inclusion and Exclusion Criteria

Adult patients seeking treatment in the Federal University of Pelotas, in need of endodontic and restorative treatment in teeth with at least one entire coronal wall remaining after endodontic procedures, were selected. In addition, patients should have good oral and general health and bilateral occlusal posterior contacts. Patient exclusion criteria were: financial limitations; untreated temporomandibular joint disorder; or extensive removable partial / complete dentures in the opposing jaw. Tooth exclusion criteria were: tooth mobility; periodontally compromised condition; or a periapical lesion that did not resolve after endodontic treatment. All participants signed written informed consent before being accepted into the study.

Randomization Procedures

All teeth were randomized and assigned to each group using a computer-generated list of random numbers. Each number was written on a white paper and placed into brown envelopes, by a researcher not involved in the study according to the treatment previously randomized. As a result, the clinician and the patient (double-blind study design) only knew which type of restoration was going to be the final restoration (direct or indirect) after cementing the post and making the resin composite restoration. Allocation only occurred after making the restoration, when the envelope was opened and if the paper had “crown” written, the crown preparation was performed. If the paper had “resin” written, no preparation was performed and the resin composite restoration was finished and polished. The randomization sequence was stratified by tooth type, anterior, premolar or molar. Due to the slow uptake of patients, blocks of 10 patients were randomized after one year of the clinical trial to minimize unbalancing.

Clinical Procedures

All root canal treatments were performed under rubber dam isolation and all materials were used according to the manufacturers’ instructions. Trained undergraduate and graduate students performed all procedures, including restorative reconstruction.

A crown-down technique was performed (2.5% sodium hypochlorite as irrigant) using files in ascending sizes. The root canals were filled with gutta-percha points (Coltene/Whaledent, Langenau, Germany) and cement (Endo-fill, Dentsply/Maillefer, Petrópolis, Brazil) by lateral and vertical condensation. The gutta-percha was immediately partially removed with a heated spreader and a #2 Gates-Glidden drill, leaving 4 mm of apical seal. Where appropriate a waiting period with temporary restoration was observed, to evaluate peri-apical healing. The post space was prepared using a calibrated bur corresponding to the glass fiber post number (#0.5 or 1, White Post DC, FGM, Joinville, SC, Brazil). After checking the fit, the posts were cleaned with alcohol and pretreated with silane (ProSil, FGM) (23), and luted according to protocol for the assigned cement. For the regular resin cement (RelyX ARC, 3M ESPE, St Paul, USA), the dentinal walls of the post space was acid-etched using 37% phosphoric acid (Condac, FGM) and an adhesive system was applied (Adper Single Bond or ScotchBond Multi Purpose - 3M ESPE) followed by insertion of the resin cement using Centrix syringe (DFL Indústria e Comércio S.A., Rio de Janeiro, Brazil). Digital pressure was applied for 5 min excess of cement was removed and light-cured for 40 s/surface. The same procedures were performed for self-adhesive resin cement (RelyX U100, 3M ESPE), but without the adhesive. After post cementation, radiographs were taken to check the location of the post. All heads of the posts were 2 mm sub-occlusal.

Direct restorations were made using a microhybrid resin composite (ScotchBond Multi Purpose + Filtek Z250, 3M ESPE) with an incremental technique. Each increment was light-cured for 40s. All restorations were immediately finished with fine and ultra-fine diamond finishing-burs (KG Sorensen, Barueri, SP, Brazil) under water spray, and polished with Sof-Lex discs (3M ESPE) and 0.1μm particle size diamond paste 1 to 7 days later.

For indirect restorations, the core restoration was made with Scotchbond MP and Filtek Z250 using an incremental technique (curing 40 sec/layer) with at least 2 mm composite covering the post. For the metal-ceramic crown preparation diamond burs were used. All margins were at gingival level and finished with a chamfer outline. The preparation had a space of at least 1.5 mm in all vertical surfaces and 2 mm for the occlusal surface. Impressions were made (Impregum F, 3M ESPE) and the same laboratory made all crowns using cobalt-chromium alloy and ceramic. A temporary acrylic resin crown was placed using calcium hydroxide cement (Dycal, Dentsply, Petrópolis, RJ, Brazil). All crowns were placed using the self-adhesive cement RelyX U100.

Evaluation Parameters

The date of crown cementation or completed restorative treatment for each patient was considered as baseline. Patients were recalled after 6 months and 1 year, and then yearly up to 5 years for clinical and radiographic examination. A single trained and calibrated independent examiner (Kappa 0.92) carried out the evaluation following the FDI criteria including esthetic, functional and biological properties, with a threshold for failure between scores 3 (clinically sufficient / satisfactory) and 4 (clinically unacceptable) (24). In addition, the type of failure was also recorded. If the patient returned to the evaluation with a tooth with a debonded post and/or restoration, or even extracted, the time of failure was based on patient's report.

Statistical Analysis

Statistical analyses were performed using SPSS 22 for MAC (SPSS Inc, Chicago, IL). Descriptive analyses were used to describe the patients / teeth included in the study and the reasons for failure. The longevity of the restorations and the teeth was analyzed using Kaplan-Meier statistics and log-rank tests for differences between groups ($p < 0.05$). Type of tooth (anterior, premolar or molar) and position (mandible or maxilla) were assessed. Absolute and relative failures were considered in the analysis, i.e. success (clinically acceptable without repair) and survival (tooth present, including repair). Annual failure rates were also calculated.

Results

Between July 2009 and June 2014 69 patients with need of endodontic treatment in a severely damaged tooth were screened by the Department of Operative Dentistry, Federal University of Pelotas, Brazil. Twenty-two patients were excluded on the basis of the inclusion/exclusion criteria or as they declined to participate. The study group consisted of 47 patients, of whom 10 patients had two teeth treated resulting in a total of 57 included teeth. Fourteen anterior teeth (4 resins and 10 crowns), 21 premolars (12 resins and 9 crowns) and 22 molars (14 resins and 8 crowns) were restored. No patients were lost during the follow-up period (100% recall rate, Figure 1). The characteristics of the included teeth can be found in table 1.

Table 1
Descriptive analysis of patients and teeth involved in the trial.

		Composite Resin	Metal-Ceramic Crown	All Data
Follow-Up	Months	27.8 (±13.8)	30.96 (±14.1)	29.3 (±13.9)
Patient's Age	Years	39.8 (±12.3)	45.63 (±9.3)	42.6 (±11.2)
Gender (Teeth)	Female	23	24	47
	Male	7	3	10
Arch Location	Upper	18	20	38
	Lower	12	7	19
Type of Tooth	Anterior	4	10	14
	Premolar	12	9	21
	Molar	14	8	22
Remaining Walls	1	12	18	29
	2	12	6	17
	3	7	2	9
	4	1	1	2

Follow up time ranged between 13 and 59 months, with a mean of 2.5 years. One absolute failure (extraction) due to root fracture was recorded in the composite resin group after 11 months. For restoration success, one failure was observed for the metal-ceramic crown group. However, 8 direct restorations failed: 7 restoration fractures and 2 secondary caries – with one tooth presenting both types of failure (supplementary appendix). Kaplan-Meier survival curves for the main comparison of composite vs crown restoration are shown for tooth survival (Figure 2A) and restoration success (Figure 2B). Survival curves for the secondary comparison of post cementation method are shown in Figure 2C for restoration success. The three properties of the FDI clinical criteria showed unacceptable scores for composite resin – esthetic (4.2%), functional (13%) and biological (13%). The percentages for all criteria are presented in table 2.

Log-rank tests demonstrated a statistically significant difference between the restoration types (p=0.022) for the success outcome and no difference for survival (p=0.344). For type of tooth (Figure 2C) and position in upper or lower jaw no statistically significant differences in success were found (p=0.970 and p=0.797, respectively). The calculated post hoc power analysis was 83%.

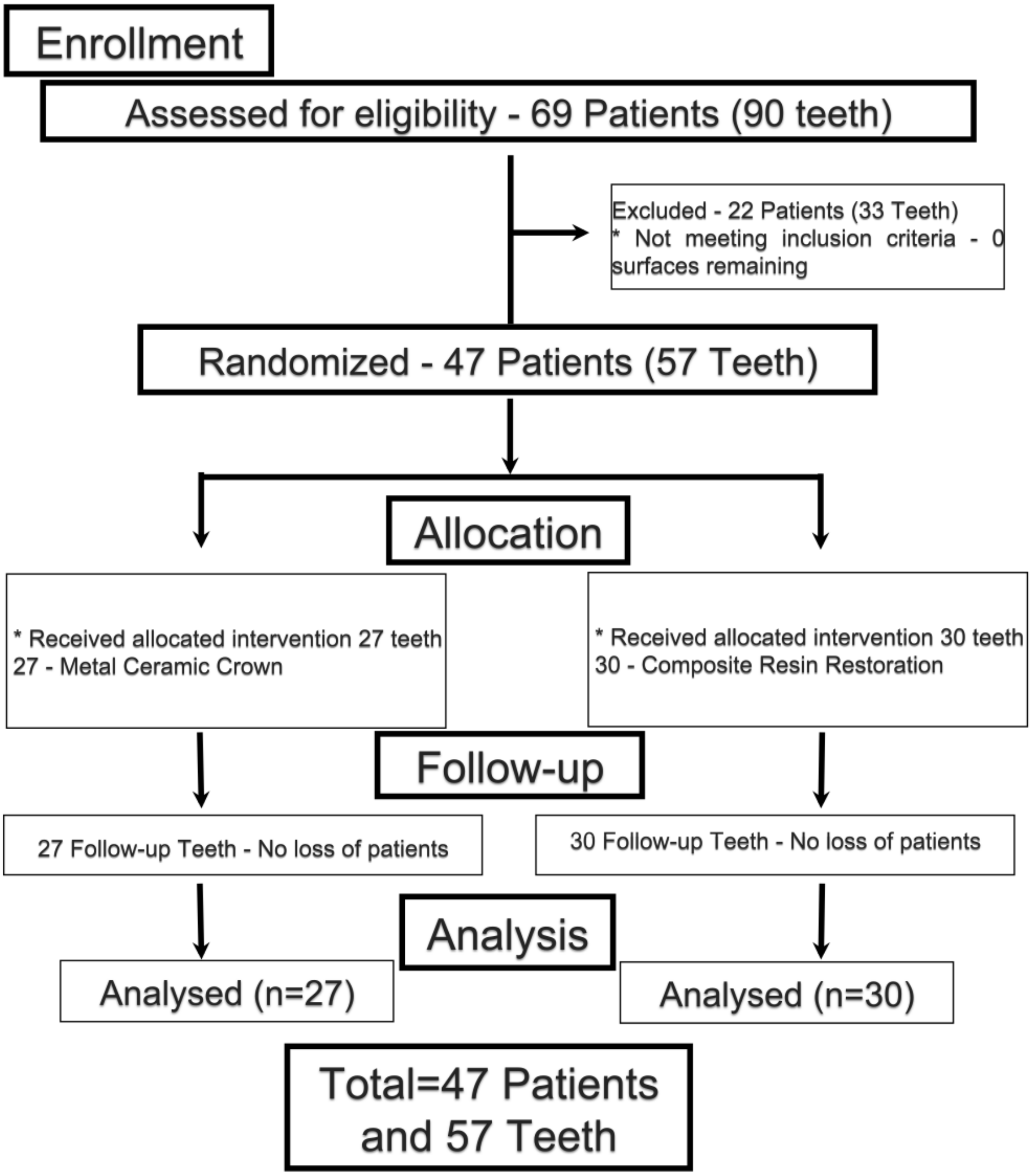

Figure 1. Flowchart of the trial phases.

The annual failure rate (AFR) for crowns at 55 months was 0% (no failures recorded), with 57.7% of the sample evaluated at 30 months, 26.9% evaluated at 42 months and 3.8% evaluated at 55 months. For resin composite restorations, the annual failure rate was 1.4% at 30 months, 1.0% at 42 months and 0.7% at 57 months, with 48.3 % of the sample evaluated at 30 months, 17.2% evaluated at 42 months and 3.4% evaluated and 57 months. The general AFR was 0.92% after 50 months for success of the restorations, with 1.83% for the composite group and 0.26% for the metal-ceramic crown group.

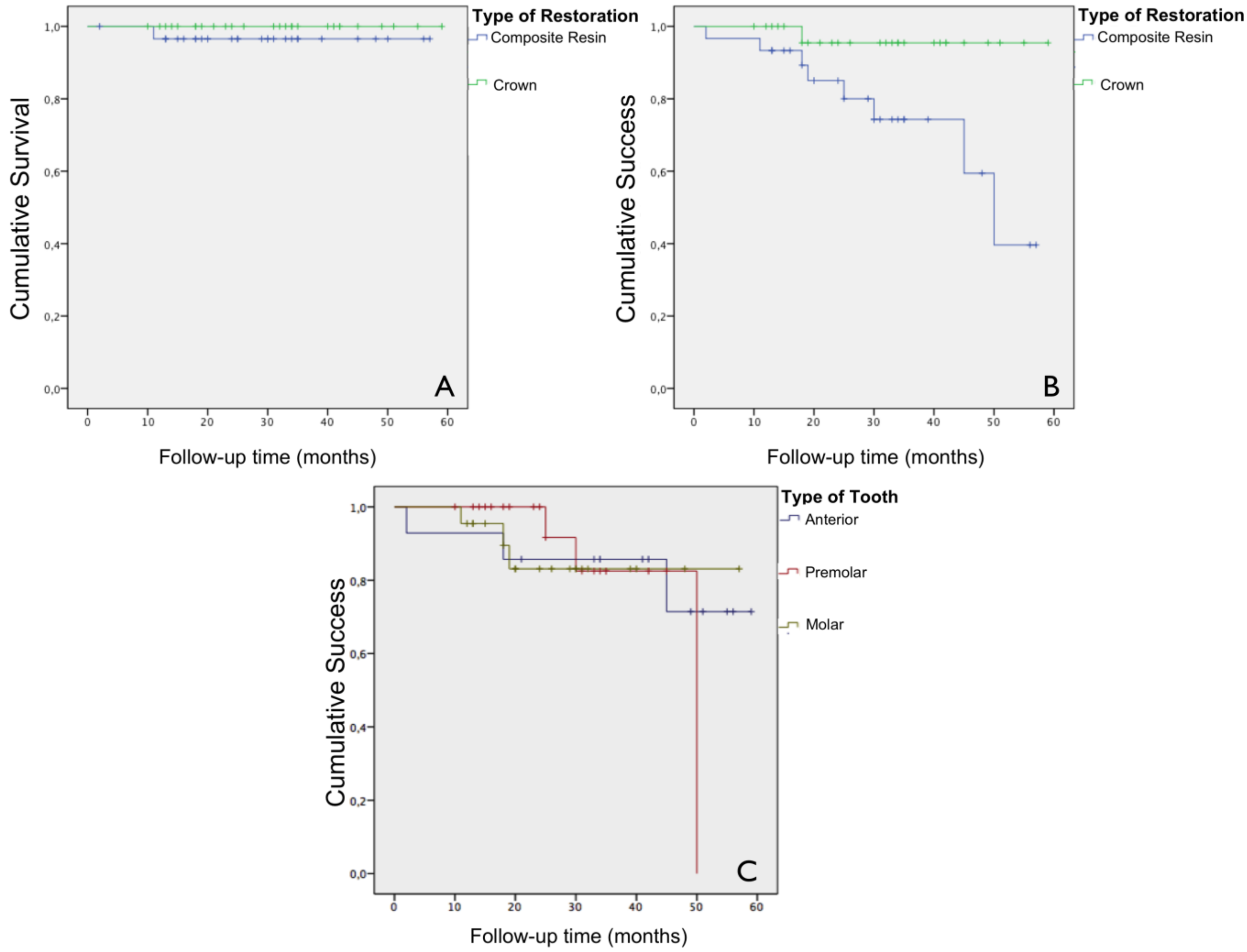

Figure 2. Kaplan-Meier survival curves presenting the survival of the tooth (A), the success of restoration (B) and according to the type of tooth (C).

Table 2
FDI clinical criteria percentages for esthetic, functional and biological properties.

A. Esthetic Properties	1. Surface luster		2a. Staining—surface		2b. Staining—margin		3. Color match and translucency		4. Esthetic anatomical form	
	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown
1 Clinically excellent/very good	70.8	100	62.5	100	58.3	95.5	54.2	100	66.7	100
2 Clinically good	25	0	33.3	0	37.5	4.5	33.3	0	25	0
3 Clinically sufficient/satisfactory	0	0	0	0	0	0	8.3	0	4.2	0
4 Clinically unsatisfactory	0	0	0	0	0	0	0	0	0	0
5 Clinically poor	4.2	0	4.2	0	4.2	0	4.2	0	4.2	0
Overall esthetic score	Acceptable esthetically—Resin: 95.8% Crown: 100%						Not acceptable—Resin: 4.2% Crown: 0%			

B. Functional Properties	5. Fracture of material and retention		6. Marginal adaptation		7a. Occlusal contour and wear—qualitatively		7b. Occlusal contour and wear—quantitatively		8a. Approximal anatomical form—contact point		8b. Approximal anatomical form—contour		9. Radiographic examination		10. Patient's View	
	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown
1 Clinically excellent/very good	78.3	100	73.9	100	75	100	79.2	100	83.3	100	83.3	100	95.2	100	83.3	100
2 Clinically good	4.3	0	17.4	0	16.7	0	16.7	0	8.3	0	8.3	0	0	0	4.2	0
3 Clinically sufficient/satisfactory	4.3	0	0	0	4.2	0	0	0	4.2	0	4.2	0	0	0	8.3	0
4 Clinically unsatisfactory	0	0	4.3	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Clinically poor	13	0	4.3	0	4.2	0	4.2	0	4.2	0	4.2	0	4.8	0	4.2	0
Overall functional score	Acceptable function—Resin: 87% Crown: 100%								Not acceptable—Resin: 13% Crown: 0%							

C. Biological Properties	11. Postoperative (hyper-) sensitivity and tooth vitality		12. Recurrence of caries, erosion, abfraction		13. Tooth integrity (enamel cracks, tooth fractures)		14. Periodontal response		15. Adjacent mucosa		16. Oral and general health	
	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown	Resin	Crown
1 Clinically excellent/very good	95.7	100	90.9	100	87.0	100	70.8	90.9	70.8	90.9	82.6	90.9
2 Clinically good	0	0	0	0	0	0	16.7	0	20.8	9.1	17.4	9.1
3 Clinically sufficient/satisfactory	0	0	0	0	0	0	8.3	9.1	4.2	0	0	0
4 Clinically unsatisfactory	0	0	4.5	0	4.3	0	0	0	0	0	0	0
5 Clinically poor	4.3	0	4.5	0	8.7	0	4.2	0	4.2	0	0	0
Overall biological score	Acceptable biologically—Resin: 87% Crown: 100%						Not acceptable—Resin: 13% Crown: 0%					

Discussion

After maximum follow up time of 5 years (mean 2.5 years) of clinical service, metal-ceramic crowns and direct composite restorations performed equally in endodontically treated teeth that received a glass fiber post and had at least one remaining coronal wall, at least if we consider tooth survival. In this study, identical posts were used to equalize this effect after cementing a crown or placing a direct restoration. To our knowledge, this is the first randomized clinical trial including all tooth types and severely broken down teeth comparing crowns vs composite restorations. These results are important, considering that a systematic review (17) concluded that there is no evidence to support the best restorative material to restore endodontically treated teeth. In addition, these findings support previous reports on the effectiveness of endodontic treatment (25,26) as well as glass fiber post cementation (1,21,27).

Nevertheless, an important issue of the present study must be emphasized: the presence of at least one remaining coronal wall. This coronal wall provides a surface for predictable composite resin bonding and enhances the ferrule in cases of indirect restorations, thus strengthening the tooth-restoration complex, improving resistance (27-29) and increasing survival probability (1,2,31,32). Although overall tooth survival was close to 100%, metal-ceramic crowns presented significantly higher restoration success than composite resin restorations. These results are expected to be reflective of the relatively short (mean 2.5 years) follow-up time. In a study analyzing survival and success for up to 9 years, restoration success for composite restorations and new crowns was similar, but after about 5 years crown failure tended to impact on tooth survival significantly more, probably due to higher number of catastrophic failures as compared to composites (15). It is important to highlight however, that the previous statement was based on a retrospective study, and therefore this is a hypothesis yet to be tested. The composite restorations in the present study were made by no-experienced practitioners (graduate and post-graduate students), and do not match the good results achieved for composites in studies where an experienced clinician performed the restorations (13,15). As all teeth presented remaining wall, a complete or incomplete ferrule was always present, which has a positive effect on fracture resistance of endodontically treated teeth (33), even if the amount of residual coronal structure was demonstrated as having no influence in the risk of failure (34). Also, teeth included had 1 to 3 intact surfaces. To rule out the possibility of this detail influence the outcomes, a Log-rank test was applied for number of intact surfaces, and no statistically significant difference was found for tooth or restoration survival.

Mannocci et al. (3) concluded that after 3 years, metal-ceramic crowns did not enhance the clinical performance of endodontically treated teeth compared with direct composite. In that study, all failures (4 composites and 3 crowns) were replaced, with the maintenance of the tooth in clinical service. It may be inappropriate to compare the management of failures of the referred study with the present study since only the description of the type of failure is not enough for this judgment. Still, we chose for a repair against replacement due to the fact that all failures were considered reparable and repairs can considerably enhance the longevity especially in cases of secondary caries (14). Secondary caries was not the major reason of failure, but the only other reason for failure was restoration fracture, previously described as the most common type (35).

Due to small number of events (failures), a cox-regression model could not be used. Instead, survival curves followed by log-rank tests were carried out to verify the influence of isolated variables. Although no difference in survival was found, survival curves followed the conventional curves found in other studies, including the reparable events as failures. Type and position of the tooth in the arch did not influence the success of restoration. This is in contrast with Da Rosa Rodolpho et al. (13), who found 3 times more risk of failure for restorations placed in lower molars compared with upper premolars. Skupien et al. (15) showed that restorations in endodontically treated premolars and anterior teeth were more successful compared with those in molars, but emphasized that the influence of tooth type on longevity is not well established. Sample size calculation for this study was performed considering the type of restoration as the primary outcome. Additional comparisons were performed but a higher number of teeth may be needed to find effects of additional variables. Also, the analysis of tooth type effect was complicated by the unequal distribution of tooth types over the subgroups, and could be cited as a limitation of our RCT. Thus, due to the difficulties in uptake of patients, a randomization change had to be made as reported in materials and methods.

Other factors, such as patient age and gender, or number of remaining coronal walls and contact with an antagonist still have to be evaluated.

Conclusion

In conclusion, restorations placed on endodontically treated teeth presented acceptable survival rates. However, indirect restorations provided higher acceptable clinical performance and lower need for re-intervention.

References

1. Bitter K, Noetzel J, Stamm O, Vaudt J, Meyer-Lueckel H, Neumann K, Kielbassa AM. Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: preliminary results of a mean period of 32 months. J Endod. 2009;35(11):1477-82.
2. Ferrari M, Vichi A, Fadda GM, Cagidiaco MC, Tay FR, Breschi L, Polimeni A, Goracci C. A randomized controlled trial of endodontically treated and restored premolars. J Dent Res. 2012;91(7 Suppl):72S-78S.
3. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent. 2002;88(3):297-301.
4. Mannocci F, Qualtrough AJ, Worthington HV, Watson TF, Pitt Ford TR. Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: five-year results. Oper Dent. 2005;30(1):9-15.
5. Hansen EK, Asmussen E. In vivo fractures of endodontically treated posterior teeth restored with enamel-bonded resin. Endod Dent Traumatol. 1990;6(5):218-25.
6. Ahrari F, Nojoomian M, Moosavi H. Clinical evaluation of bonded amalgam restorations in endodontically treated premolar teeth: a one-year evaluation. J Contemp Dent Pract. 2010;11(5):9-16.
7. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent. 2007;35(10):778-86.
8. van Dijken JW, Hasselrot L, Ormin A, Olofsson AL. Restorations with extensive dentin/enamel-bonded ceramic coverage. A 5-year follow-up. Eur J Oral Sci. 2001;109(4):222-9.
9. Lanza A, Aversa R, Rengo S, Apicella D, Apicella A. 3D FEA of cemented steel, glass and carbon posts in a maxillary incisor. Dent Mater. 2005;21(8):709-15.
10. Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post.

Biomaterials. 2002;23(13):2667-82.

11. Magne P, Goldberg J, Edelhoff D, Güth JF. Composite Resin Core Buildups With and Without Post for the Restoration of Endodontically Treated Molars Without Ferrule. Oper Dent. 2016;41(1):64-75.
12. van Dijken JW. Durability of resin composite restorations in high C-factor cavities: a 12-year follow-up. J Dent. 2010;38(6):469-74.
13. Da Rosa Rodolpho PA, Donassollo TA, Cenci MS, Loguércio AD, Moraes RR, Bronkhorst EM, Opdam NJ, Demarco FF. 22-year clinical evaluation of the performance of two posterior composites with different filler characteristics. Dent Mater. 2011;27(10):955-63
14. Opdam NJ, Bronkhorst EM, Loomans BA, Huysmans MC. Longevity of repaired restorations: a practice based study. J Dent. 2012;40(10):829-35.
15. Skupien JA, Opdam NJ, Winnen R, Bronkhorst E, Kreulen C, Pereira-Cenci T, Huysmans MC. A Practice-Based Study on the Survival of Restored Endodontically Treated Teeth. J Endod. 2013;39(11):1335-40.
16. Fedorowicz Z, Carter B, de Souza RF, Chaves CA, Nasser M, Sequeira-Byron P. Single crowns versus conventional fillings for the restoration of root filled teeth. Cochrane Database Syst Rev. 2012 16;5:CD009109.
17. Sequeira-Byron P, Fedorowicz Z, Carter B, Nasser M, Alrowaili EF. Single crowns versus conventional fillings for the restoration of root-filled teeth. Cochrane Database Syst Rev. 2015 25;9:CD009109.
18. Cagidiaco MC, García-Godoy F, Vichi A, Grandini S, Goracci C, Ferrari M. Placement of fiber prefabricated or custom made posts affects the 3-year survival of endodontically treated premolars. Am J Dent. 2008;21(3):179-84.
19. Fennis WM, Kuijs RH, Roeters FJ, Creugers NH, Kreulen CM. Randomized control trial of composite cuspal restorations: five-year results. J Dent Res. 2014;93(1):36-41
20. King PA, Setchell DJ, Rees JS. Clinical evaluation of a carbon fibre reinforced carbon endodontic post. J Oral Rehabil. 2003;30(8):785-9.
21. Naumann M, Sterzenbac G, Alexandra F, Dietrich T. Randomized controlled clinical pilot trial of titanium vs. glass fiber prefabricated posts: preliminary results after up to 3 years. Int J Prosthodont. 2007;20(5):499-503.
22. Schmitter M, Rammelsberg P, Gabbert O, Ohlmann B. Influence of clinical baseline findings on the survival of 2 post systems: a randomized clinical trial.

Int J Prosthodont. 2007;20(2):173-8.

23. Moraes AP, Sarkis-Onofre R, Moraes RR, Cenci MS, Soares CJ, Pereira-Cenci T. Can Silanization Increase the Retention of Glass-fiber posts? A Systematic Review and Meta-analysis of In Vitro Studies. Oper Dent. 2015;40(6):567-80.

24. Hickel R, Peschke A, Tyas M, Mjör I, Bayne S, Peters M, Hiller KA, Randall R, Vanherle G, Heintze SD. FDI World Dental Federation - clinical criteria for the evaluation of direct and indirect restorations. Update and clinical examples. J Adhes Dent. 2010;12(4):259-72.

25. Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of non-surgical root canal treatment: part 2: tooth survival. Int Endod J. 2011;44(7):610-25

26. Setzer FC, Kim S. Comparison of long-term survival of implants and endodontically treated teeth. J Dent Res. 2014;93(1):19-26.

27. Grandini S, Goracci C, Tay FR, Grandini R, Ferrari M. Clinical evaluation of the use of fiber posts and direct resin restorations for endodontically treated teeth. Int J Prosthodont. 2005;18(5):399-404.

28. Mangold JT, Kern M. Influence of glass-fiber posts on the fracture resistance and failure pattern of endodontically treated premolars with varying substance loss: an in vitro study. J Prosthet Dent. 2011;105(6):387-93.

29. Valdivia AD, Raposo LH, Simamoto-Júnior PC, Novais VR, Soares CJ. The effect of fiber post presence and restorative technique on the biomechanical behavior of endodontically treated maxillary incisors: an in vitro study. J Prosthet Dent. 2012;108(3):147-57.

30. Zicari F, Van Meerbeek B, Scotti R, Naert I. Effect of ferrule and post placement on fracture resistance of endodontically treated teeth after fatigue loading. J Dent. 2013;41(3):207-15.

31. Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M. Clinical performance of fiber post restorations in endodontically treated teeth: 2-year results. Int J Prosthodont. 2007;20(3):293-8.

32. Signore A, Kaitsas V, Ravera G, Angiero F, Benedicenti S. Clinical evaluation of an oval-shaped prefabricated glass fiber post in endodontically treated premolars presenting an oval root canal cross-section: a retrospective cohort study. Int J Prosthodont. 2011;24(3):255-63.

33. Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. J Endod. 2012;38(1):11-9
34. Juloski J, Fadda GM, Monticelli F, Fajó-Pascual M, Goracci C, Ferrari M. Four-year Survival of Endodontically Treated Premolars Restored with Fiber Posts. J Dent Res. 2014;93(7 Suppl):52S-58S.
35. Demarco FF, Corrêa MB, Cenci MS, Moraes RR, Opdam NJ. Longevity of posterior composite restorations: not only a matter of materials. Dent Mater. 2012;28(1):87-101.

Chapter 7

General Discussion, conclusions and recommendations

With a view to the general lack of scientific evidence to treatment options, and the real possibility of iatrogenic damage, minimally invasive options should always be considered in dentistry. When a restoration in an endodontically treated tooth is planned, it should be kept in mind that this tooth has already suffered cumulative injuries and that many known and unknown factors may influence long-term survival of the tooth. Issues regarding restorative procedures of ETT were the main focus of this thesis. No comparisons between vital and non-vital teeth were made, and the reader needs to realize that all the results presented are related to non-vital teeth.

There are many possible methodologies to evaluate any of the most distinct clinical situations occurring in ETT. In scientific knowledge development, usually a quality pyramid of evidence is used from laboratory studies to clinical studies, reviews and finally, meta-analysis as the best source of evidence to inform the decision-making process (1,2). In this context, several methodologies were explored in the present thesis to better understand the factors influencing restorations success and tooth survival for ETT, attempting to support the clinical decision making procedure in such cases.

As set out in the introduction, non-vital teeth usually present a large coronal destruction, resulting in less remaining intact tissue and, consequently, a compromised prognosis (3). These teeth present a challenge in restorative dentistry, with often insufficient remaining coronal structure to retain the restorative material intra-coronally and thus leaving the dentist to decide whether and how to find retention in the root. Chapter 5 describes two different configurations of the remaining tooth structure: presence of high or low outline (sometimes referred to as ferrule) and presence of a remaining cusp or not. These configurations were then restored with or without a glass fiber post. The statistical analysis demonstrated that the higher outline resulted in a higher fracture resistance of composite restored ETT, as did post placement. However, the latter increased threefold the risk of catastrophic failures. This finding does not imply a contraindication of posts, but it should promote careful clinical decision making. Although no crowns were used in this study, this does not lessen the study's clinical relevance, as coronal coverage is no longer the most frequent choice. Moreover, clinical relevance was enhanced by the samples being submitted to thermal and mechanical ageing, simulating time of clinical function. In Chapter 3, the use of posts was evaluated in a retrospective clinical study. After 7 years of clinical function, restorations retained with posts had an annual failure rate 3 times higher than restorations placed without a post. However, this effect was not confirmed in the multivariate analysis, and, more importantly, indication bias may have been essential in determining a possible survival difference between posted and non-posted teeth.

It has been hypothesized in the literature that posts 'reinforce' teeth with extensive destruction and thereby increases longevity. In our meta-analysis in Chapter 2 we demonstrated that when composite resin restorations or crowns are placed in combination with a post, 10-year survival increases with about 20%. However, there are many post configurations to choose from, such as cast metal, prefabricated metal and fiber reinforced resin posts, each with a different anticipated prognosis. Although cast metal posts have a good resistance and adaptation (4), they have many disadvantages, such as inhomogeneous stress distribution (5,6), and aesthetic and biological problems (4,7). Thus, the general view seems to be in favour of the so called fiber posts, since they have an elastic modulus similar to that of dentine, thereby improving stress distribution (5,8), and decreasing the risk of catastrophic failure (9). From metal posts it is expected that they will show more fractured teeth while failing (5,6). Although post debonding is the most common type of failure (10), it would be more than interesting to expand the present analyses to failure behavior. We had to limit our review to survival of ETT and data analyses on the level of type of failure will get complicated. However, there is an RCT (11) comparing survival of glass fiber and cast metal posts, which demonstrated similar clinical performance for both type of retainers after 3 years. A systematic review on in vitro studies showed higher fracture resistance for root restored with metal post compared to fiber post, but with higher incidence of catastrophic failures with the former (12). Yet, another clinical systematic review did not show significant differences for root fractures incidence between metal and fiber posts (13). Given the better relevance of clinical studies over laboratory simulations, there is no preference between the two options.

The choice (or not) of a post has consequences and others factors must also be evaluated such as the amount of coronal remaining tooth structure, the presence of a ferrule, the location of the tooth, and occlusion features, as the authors of the reviews suggested. It appears that restorations behave quite differently, and different factors influence survival, based on their location in either anterior or posterior teeth, and possibly even premolar and molar teeth present different conditions for survival.

Two recent reviews evaluated longevity and reasons for failure in anterior and posterior composite restorations separately (14,15). For posterior restorations, the main reasons for failures were caries and fracture with an annual failure rate of 1.8 % at 5 years and 2.4 % after 10 years of service (15). The failure behavior in anterior restorations presented less secondary caries and more restorations being replaced for other reasons such as esthetic appearance, with a failure rate varying from 0 to 4.1 % (14). Chapters 3 and 4 bring information regarding longevity of endodontically treated teeth in a retrospective study in dental practice. After 5 years of clinical service, composites presented an AFR of 3.0 % while crowns showed an AFR of 1.9 %. Some 3.7 years later, after 8.7 years of clinical service, the AFR increased to 4 % and 4.1 %, respectively. Although we did not perform AFR calculation for anterior and posterior teeth separately, tooth type was shown to have a significant influence on risk for restorative failure, with molars demonstrating an increased risk for failure compared to premolars and anterior teeth.

As far as clinical relevance is concerned, ‘survival’ is probably a more important outcome than ‘restoration success’. Factors influencing tooth survival are therefore very important, even if the factor does not seem of direct influence to the restoration behavior. So we found that every extra millimeter of maximum pocket depth of the tooth increased the risk of failure of the restored ETT with 60 %. The same trend was found for the tooth being the last in the arch, which resulted in a 3 times higher risk of failure. The number of teeth in the dentition and the number of decayed teeth were established to be favorable factors for longevity for either restoration or teeth. A periodontally compromised situation is often cited as a contra-indication for extensive restorative procedures as it leads to a reduced prognosis, just as ETT by them selves (16). In Chapter 4 we showed that periodontal disease, even in its more early stages, in non-vital teeth may act as an additional factor determining longevity and in clinical practice we might be reluctant to indicate biologically and financially costly indirect restorations in such compromised teeth. Although retrospective studies such as these bring valuable results, especially with regard to ‘real world dentistry’, the major limitation in this specific study was the absence of recorded reasons for failure, reducing the possibilities for comparison with other studies.

Attempting to contribute to the volume of high value evidence for the best option to restore an endodontically treated tooth, Chapter 6 describes a randomized clinical trial (RCT) standardizing to a very high degree restorative variables that could influence survival of restorations. For that, a set of rigorous exclusion/inclusion criteria was employed. All included teeth had at least one intact surface and a foundation restoration was made with a glass fiber post followed by a composite core. The clinical crown was restored with a direct (composite resin) or indirect (metal-ceramic crown) restoration according to the randomization process. Only one absolute failure was found (composite group). However, nine relative failures were recorded, eight in the direct composite group (7 restoration fractures and twice secondary caries – one tooth presented both types of failure) and one in the crown group (debonding). Thus, it seems that crowns require less maintenance during service than their resin composite counterparts. All teeth/restorations received a repair and no post-related intervention was needed. Although the endodontic treatment and the necessity to remove internal tooth structure is a factor that affects restoration survival (17), either direct or indirect restorations achieved acceptable survival rates. In most cases of failure, repair was still possible. Restoration repair has been shown to enhance longevity of dental restorations (18) and is considered an optimal approach, especially for posterior resin composite restorations (19). A previous RCT also reported good survival rates for both types of restoration, but observed failures were decementation of posts and development of marginal gaps (20). If we look at the results in Chapter 2 from this perspective, considering the longevity of crowns and composite resin restorations, irrespective of the use of a post, the results for both types of restoration are quite similar during the first four years of function. Thereafter crowns appear to outperform composite. This does not mean that all ETT must be restored with crowns. In our meta-analysis a high volume of the data came from retrospective studies and bias by indication can be introduced: for teeth with a dramatic loss of tooth tissue, the dentist may advice not to make a crown because of the negative cost-effect ratio. In these cases the basic conditions for the composite restoration are obviously reduced. On the other hand, composite restorations can be indicated just for the smaller cavities. In the two RCTs that could compare the clinical functioning of composite restorations and crowns no difference in survival could be found (20,21). Those two studies were of short duration (2-3 years), confirming our simulations. Apparently, factors as anticipated type of failure, wishes of patients, costs, and time-consuming procedures must be taken into account in the clinical decision.

Another factor that was not considered in this thesis, but may well be important in restorations placed in severely damage posterior teeth is the cuspal coverage by the restorative material. Due to access preparation, which results in a greater cuspal flexure, the probability of cuspal fracture is increased. Thus, cuspal coverage, which is included in the indirect crown, may be a good option for the composite restoration to increase success of the restoration (22,23). As with amalgam restorations and thin remaining cusps, many dentists use this technique with satisfactory results, but clinical study results are not available. As minimally invasive dentistry gains ground, we expect more scientific evidence for this approach in the future.

Finally, we conclude that it is unlikely that a single optimal restorative approach for all ETT can be developed. Each case must be evaluated individually, considering for example the amount of remaining structure, the condition of both of the tooth and the entire dentition, the risks and possibilities of post cementation, the patient's wishes and possibilities, and the caries risk. The data from our laboratory study seem to indicate that in cases with little tissue loss, a post can be omitted, but should be indicated in cases with severely damaged teeth. A similar reasoning applies to the restoration of the clinical crown: little tissue loss in ETT may be treated with composite, large defects better benefit of an indirect restoration. Even though ETT have a compromised prognosis, restoration is certainly a viable option and survival results are acceptable, especially when risk factors are taken into account, as well as the possibilities for repair after failure.

Conclusions:

Considering the results for ETT found on this thesis, the following conclusions can be drawn:

- In the first few years after placement, no difference in restoration longevity could be observed between full coverage crowns and large composite restorations. In the long term crowns appear to perform better.
- Composite resin restorations need more intervention compared to indirect crowns during lifetime.

- A post increases the survival rate of the restored ETT, but the risk of fatal fracture is also increased.
- The fewer remaining teeth and the more caries activity in a patient's dentition, the lower the survival probability of an ETT.
- Periodontal pocket depth is negatively associated with survival of the ETT.

References

1. Berlin JA, Golub RM. Meta-analysis as evidence: building a better pyramid. JAMA. 2014 13;312(6):603-5.

2. Ho PM, Peterson PN, Masoudi FA. Evaluating the evidence: is there a rigid hierarchy? Circulation. 2008 14;118(16):1675-84.

3. Nagasiri R, Chitmongkolsuk S. Long-term survival of endodontically treated molars without crown coverage: a retrospective cohort study. J Prosthet Dent. 2005;93(2):164–70.

4. Cheung W. A review of the management of endodontically treated teeth. Post, core and the final restoration. J Am Dent Assoc. 2005;136(5):611–9.

5. Joshi S, Mukherjee A, Kheur M, Metha A. Mechanical performance of endodontically treated teeth. Finite Elem Anal Des. 2001;37(8):587–601.

6. Tokasvul S, Zor M, Toman M, Gungor MA, Nergiz I, Artunc C. Analysis of dentinal stress distribution of maxillary central incisors subjected to various post- and-core applications. Oper Dent. 2006;31(1):89–96.

7. Salameh Z, Sorrentino R, Ounsi HF, Sadig W, Atiyeh F, Ferrari M. The effect of different full-coverage crown systems on fracture resistance and failure pattern of endodontically treated maxillary incisors restored with and without glass fiber posts. J Endod. 2008;34(7):842–6.

8. Barjau-Escribano A, Sancho-Bru JL, Forner-Navarro L, Rodriguez-Cervantes PJ, Perez-Gonzalez A, Sanchez-Marin FT. Influence of prefabricated post material on restored teeth: fracture strength and stress distribution. Oper Dent. 2006;31(1):47–54.

9. Fernandes AS, Shetty S, Coutinho I. Factors determining post selection: a literature review. J Prosthet Dent. 2003;90(6):556–62.

10. Rasimick BJ, Wan J, Musikant BL, Deutsch AS. A review of failure modes in teeth restored with adhesively luted endodontic dowels. J Prosthodont. 2010;19(8): 639–46.

11. Sarkis-Onofre R, Jacinto Rde C, Boscato N, Cenci MS, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. J Dent. 2014;42(5):582-7.

12. Zhou L, Wang Q. Comparison of fracture resistance between cast posts and fiber posts: a meta-analysis of literature. J Endod. 2013;39(1):11-5.

13. Figueiredo FE, Martins-Filho PR, Faria-E-Silva AL. Do metal post-retained restorations result in more root fractures than fiber post-retained restorations? A systematic review and meta-analysis. J Endod. 2015;41(3):309-16.
14. Demarco FF, Collares K, Coelho-de-Souza FH, Correa MB, Cenci MS, Moraes RR, Opdam NJ. Anterior composite restorations: A systematic review on long-term survival and reasons for failure. Dent Mater. 2015;31(10):1214-24.
15. Opdam NJ, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, Gaengler P, Lindberg A, Huysmans MC, van Dijken JW. Longevity of posterior composite restorations: a systematic review and meta-analysis. J Dent Res. 2014;93(10):943-9.
16. Graetz C, Schützhold S, Plaumann A, Kahl M, Springer C, Sälzer S, Holtfreter B, Kocher T, Dörfer CE, Schwendicke F. Prognostic factors for the loss of molars - an 18-years retrospective cohort study. J Clin Periodontol. 2015;42(10):943-50.
17. van de Sande FH, Opdam NJ, Rodolpho PA, Correa MB, Demarco FF, Cenci MS. Patient risk factors' influence on survival of posterior composites. J Dent Res. 2013;92(7 Suppl):78S-83S.
18. Opdam NJ, Bronkhorst EM, Loomans BA, Huysmans MC. Longevity of repaired restorations: a practice based study. J Dent. 2012;40(10):829-35.
19. Lynch CD, Opdam NJ, Hickel R, Brunton PA, Gurgan S, Kakaboura A, Shearer AC, Vanherle G, Wilson NH. Guidance on posterior resin composites: Academy of Operative Dentistry - European Section. J Dent. 2014;42(4):377-83.
20. Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent. 2002;88(3):297-301.
21. Bitter K, Noetzel J, Stamm O, Vaudt J, Meyer-Lueckel H, Neumann K, Kielbassa AM. Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: preliminary results of a mean period of 32 months. J Endod. 2009;35(11):1477-82.
22. Cheung GS, Chan TK. Long-term survival of primary root canal treatment carried out in a dental teaching hospital. Int Endod J. 2003;36(2):117–28.
23. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent. 2002;87(3):256– 63.

Chapter 8

Summary

Summary

This thesis focused on restorations placed in endodontically treated teeth (ETT). The literature on this subject is plentiful, but also very variable in its outcomes. Thus, it is the overall aim of this thesis to further explore the success and survival of restorations in endodontically treated teeth, with a focus on the question whether posts and full coverage crowns improve the prognosis, and if so, in what circumstances. For this, initially Chapter 2 describes a systematic review and meta-analysis assessing clinical studies (prospectives and retrospectives) that used crown or composite restoration to restore endodontically treated teeth. The aim of the study was to bring together published data on the clinical prognosis of reconstructed endodontically treated teeth, with type of restoration (crown or extensive composite restoration) and additional retention (post or no post) as factors. The primary outcome variable was survival of the restorations, expressed as annual failure rate (AFR). In situations where the AFR was not present but could be calculated from the data, the paper was also included. From 1250-screened papers, 43 were included. Thirtytwo of the selected studies observed the clinical behaviour of crowns and sixteen studies included composite restorations. Cast foundation restorations with posts were applied in 12 studies, fiber posts in 26 studies, and prefabricated metal post in 10 studies. Posts were omitted in 14 study branches. For all of the four reconstruction types the study with the shortest follow-up time was 0.5 years and the longest time was 17 years. In the first ten years, for both groups with and without posts, crowns are slightly better than composites. In the meantime, when the same type of restoration was evaluated, for all periods the presence of a post means an improvement of cumulative survival rates. The study concluded that endodontically treated teeth restored with all four restoration approaches showed acceptable survival rates, but long-term evaluations seem to be in favour of crowns and the presence of a post.

The following Chapters 3 and 4 bring us information regarding restored endodontically treated teeth through a retrospective study using data from general practice environment. In both studies, longevity of the tooth and restorations placed in a general practice were evaluated. First, data from 795 ETT were analyzed using Kaplan-Meier statistics for survival of tooth/restoration and multivariate Cox

regression to assess the variables influencing on it. After a mean observation time of 4.48 years, the AFR for tooth survival and success of restorations was 1.9% and 4.9% respectively at 9.6 years. Posts had no influence on longevity while a higher number of teeth in the dentition and the presence of decay at the moment the patient entered the practice were factors of protection. The authors concluded that restorations placed on ETT showed favourable survival on restoration and tooth level in the long-term evaluation.

Whereas Chapter 3 explores more tooth and patient-related variables, Chapter 4 investigates exclusively periodontal parameters and its influence on tooth and restoration survival. Three hundred and sixty restored ETT were evaluated and general information about patients and dentitions as well as periodontal status of the tooth were used as independent variables. Success of restoration and survival of the tooth were analysed through Kaplan-Meier. Cox regression was used to assess the influence of variables on success/survival. The first step for the Cox model was the final model found in the results of the Chapter 3. For this model, the best extension with additional periodontal information was evaluated. After a mean observation time of 4.34 years, 19 teeth were extracted and 27 restorations needed repair or replacement. Cox analysis showed that every extra mm of maximum pocket depth increases the risk of loss of the ETT with 60%. In conclusion, periodontal pocket depth was found to be a significant factor in the survival of restored endodontically treated teeth.

Chapter 5 explores critical situations to restore endodontically treated teeth. The presence of remaining buccal cavity wall, amount of cervical tissue and the presence or absence of glass fiber post were assessed to verify the effect on fracture resistance and fracture type of endodontically treated restored premolars. One hundred single-rooted upper premolars were selected according to standardized root length and mesio-distal and bucco-lingual dimensions. Teeth were embedded up to 2mm below CEJ, followed by endodontic treatment and allocated according to one of four standardized preparations with either a remaining buccal wall or no wall (1.5mm width), and a high or low cervical outline (2mm above or 1mm below cemento-enamel junction - CEJ). Half of each preparation group received a glass fiber post and all groups received composite restorations according to the average dimension of the control group teeth (sound teeth with and without fatigue). Thermal and mechanical fatigue loading was performed followed by ramped loading until fracture.

A high cervical outline (417N) and the presence of a post (189N) increased fracture strength, but both factors together had an antagonistic effect of -218N, resulting not in 606N (417+189) but 388N higher strength. A post significantly increased the risk of catastrophic failure (OR=3.17; p=0.02). It was concluded that the presence of cervical dentine and, to a lesser degree, a fiber post increased fracture resistance of composite restored ETT. However, the post increased the risk of catastrophic failure, especially in the presence of a remaining cavity wall.

A randomized clinical trial comparing survival of composite resin restorations and metal-ceramic crows on endodontically treated teeth that received a glass fiber post is presented in Chapter 6. Forty-seven patients in need of endodontic and restorative treatment in teeth with at least one entire coronal wall remaining after endodontic procedures, were selected. Ten patients had two teeth treated resulting in a total of 57 included teeth. The patients were randomly allocated into two groups, according to the type of coronal restoration: metal-ceramic crown or composite resin. Descriptive analysis was performed using FDI clinical criteria and survival of restorations/teeth analyzed using Kaplan-Meier statistics and log-rank tests. Fourteen anterior teeth (4 resins and 10 crowns), 21 premolars (12 resins and 9 crowns) and 22 molars (14 resins and 8 crowns) were restored, totalling 57 restorations (30 composite resin and 27 crowns). The recall rate was 100% after a follow up time ranged between 13 and 59 months, with a mean of 29.3 months. One tooth was extracted after 11 months post-restoration due to root fracture (composite group). Eight composite restorations and one crown had reparable failures, all due to secondary caries or restoration fracture. The overall annual failure rate (AFR) was 0.92% after 50 months for success of the restorations, with 1.83% for the composite group and 0.26% for the metal-ceramic crown group. Log-rank tests demonstrated a statistically significant difference between the restoration types (p=0.022) for the success outcome and no difference for survival (p=0.344). No difference was found for type of tooth and position in upper or lower jaw (p=0.970 and p=0.797, respectively). The three properties of the FDI clinical criteria showed not acceptable scores for composite resin – esthetic (4.2%), functional (13%) and biological (13%). The study concludes that restorations placed on endodontically treated teeth presented acceptable survival rates, however, indirect restorations provided higher acceptable clinical performance and lower need for re-intervention.

Hoofdstuk 8

Samenvatting

Samenvatting

Dit proefschrift richt zich op restauraties in endodontisch behandelde gebitselementen. Er is veel literatuur over dit onderwerp, maar deze varieert sterk in uitkomst. Daarom is het doel van dit proefschrift succes en falen van restauraties in endodontisch behandelde gebitselementen nader te onderzoeken. Hierbij staat de vraag centraal of de prognose verbetert door het gebruik van stiften en volledige kronen en welke omstandigheden daar een rol bij spelen. Om deze vraag te kunnen beantwoorden worden in hoofdstuk 2 een systematische review en meta-analyse beschreven die klinische (prospectieve en retrospectieve) studies beoordeelden waarin kroon- of composietrestauraties werden toegepast om endodontisch behandelde gebitselementen te herstellen. Het doel van deze studie was om gepubliceerde gegevens over de klinische prognose van gerestaureerde endodontisch behandelde gebitselementen te verzamelen, waarbij het soort restauratie (volledige kroon of uitgebreide composietrestauratie) en additionele retentie (wel of geen wortelstift) als factoren werden gehanteerd. De primaire uitkomstvariabele was het overleven van de restauraties uitgedrukt in jaarlijks faalpercentage (annual failure rate, AFR). Indien de AFR niet voorhanden was, maar wel kon worden berekend aan de hand van de gegevens, werd het artikel eveneens opgenomen in de studie. Van de 1250 artikelen die we hebben gescreend, zijn er 43 opgenomen in de studie. In twee derde van de geselecteerde studies werd het klinische gedrag van kronen onderzocht. In 16 studies werden composietrestauraties onderzocht. Een gegoten stiftopbouw werd toegepast in 12 studies, een gegoten stiftopbouw met vezelstift werd toegepast in 26 studies, en een opbouw met geprefabriceerde metalen stiften werd toegepast in 10 studies. Stiften werden niet gebruikt in 14 studies. Voor elk van de vier restauratietypen gold dat de studie met de kortste follow-upduur een periode van 0,5 jaar en de studie met de langste follow-upduur een periode van 17 jaar hanteerde. Gedurende de eerste tien jaar gold zowel voor de groepen met als de groepen zonder stiften dat kronen een iets beter resultaat opleverden dan composiet. Ondertussen betekende de aanwezigheid van een stift een verbetering van de cumulatieve overlevingspercentages in elke periode bij een evaluatie van hetzelfde type restauratie. De conclusie van de studie luidde dat alle vier restauratiemethoden die werden gebruikt voor het herstellen van endodontisch behandelde gebitselementen resulteerden in acceptabele overlevingspercentages. De conclusie luidde echter ook dat bij lange termijn evaluaties kronen (vergeleken met composietrestauraties) en de aanwezigheid van een stift een gunstiger resultaat opleverde.

In hoofdstuk 3 en hoofdstuk 4 wordt informatie verschaft over gerestaureerde endodontisch behandelde gebitselementen aan de hand van retrospectieve studies gebaseerd op gegevens uit de algemene praktijk. In beide studies werd de levensduur van het gebitselement en de restauraties die waren verricht in een algemene praktijk geëvalueerd. Daartoe werden eerst de gegevens van 795 endodontisch behandelde gebitselementen geanalyseerd aan de hand van de Kaplan-Meier methode om de overleving van het gebitselement alsmede de restauratie in kaart te brengen en vervolgens werd een multivariate Cox regressieanalyse uitgevoerd om de variabelen die hierop van invloed waren vast te stellen. Met een gemiddelde observatieperiode van 4,48 jaar was de AFR voor de overleving van het gebitselement en het slagen van restauraties 1,9% respectievelijk 4,9% na 9,6 jaar. Stiften waren niet van invloed op de levensduur, terwijl een groter aantal elementen in het gebit en de aanwezigheid van noodzakelijk restauratief werk op het moment dat de patiënt in de praktijk kwam beschermende factoren waren. De auteurs concludeerden dat restauraties die waren verricht in endodontisch behandelde gebitselementen een gunstige overleving van de restauratie en het gebitselement lieten zien bij lange termijn evaluatie.

In tegenstelling tot hoofdstuk 3, waarin gebitselement- en patiëntgerelateerde variabelen werden onderzocht, werden in hoofdstuk 4 uitsluitend parodontale parameters en hun effect op de overleving van het gebitselement en de restauratie bestudeerd. Er werden 360 gerestaureerde endodontisch behandelde gebitselementen geëvalueerd. Algemene informatie over de patiënten en hun gebit alsmede de parodontale toestand van het gebitselement werden gebruikt als onafhankelijke variabelen. Het slagen van de restauratie en het overleven van het gebitselement werden geanalyseerd aan de hand van de Kaplan-Meier methode. De Cox regressieanalyse werd toegepast om het effect van de variabelen op het slagen/overleven vast te stellen. De eerste stap van het Cox-model was het laatste model uit de resultaten van hoofdstuk 3. Bij dit model werd de beste extensie met aanvullende parodontale informatie geëvalueerd. Na een gemiddelde observatieperiode van 4,34 jaar werden 19 tanden getrokken en behoefden 27 restauraties reparatie of vervanging. De Cox-analyse wees uit dat iedere extra millimeter maximale pocketdiepte de kans om het endodontisch behandelde gebitselement te verliezen met 60% deed toenemen. Concluderend kan worden gesteld dat de parodontale pocketdiepte een significante factor bleek te zijn bij de overleving van gerestaureerde endodontisch behandelde gebitselementen.

In hoofdstuk 5 werd in een laboratoriumstudie onderzocht welke omstandigheden beslissend zijn bij het restaureren van endodontisch behandelde gebitselementen. De aanwezigheid van een overgebleven buccale caviteitwand, de hoeveelheid cervicaal weefsel en de aan- of afwezigheid van een glasvezelstift waren de variabelen, waarbij het effect op de breukweerstand en het breuktype van endodontisch behandelde gerestaureerde premolaren werd onderzocht. Honderd eenwortelige bovenpremolaren werden geselecteerd en gestandaardiseerd op wortellengte en mesiodistale en buccolinguale dimensies. Tanden werden vastgezet in hars op een niveau 2 mm onder de glazuur-cementgrens, en een endodontische behandeling werd uitgevoerd. Vervolgens werden elementen verdeeld over een van de vier gestandaardiseerde preparatievormen met of zonder overgebleven buccale wand (1,5 mm breed), en een hoge of lage cervicale preparatiediepte (2 mm boven of 1 mm onder de glazuur-cementgrens). De helft van elke preparatiegroep kreeg een glasvezelstift, en bij alle groepen werden composietrestauraties gemaakt. De controlegroep bestond uit gave gebitselementen met dezelfde afmetingen. Na cyclische en thermische belasting werd de breuksterkte van de samples bepaald. Een hoge cervicale outline (417 N) en de aanwezigheid van een stift (189 N) deden de breuksterkte toenemen. Deze factoren hadden samen echter een antagonistisch effect van -218 N. Hierdoor resulteerde er niet een grotere sterkte van 606 N (417 + 189), maar van 388 N. Door een stift nam de kans op een fatale mislukking significant toe (OR=3.17; p=0,02). Er werd geconcludeerd dat door de aanwezigheid van cervicaal dentine en in mindere mate van een vezelstift de breukweerstand van met composiet gerestaureerde endodontisch behandelde gebitselementen toenam. Door de stift nam de kans op een fatale mislukking echter toe, met name indien er wel een overgebleven caviteitwand aanwezig was.

In hoofdstuk 6 wordt een gerandomiseerde klinische studie gepresenteerd waarbij de overleving van kunstharscomposietrestauraties vergeleken werd met die van metaalkeramische kronen op endodontisch behandelde gebitselementen die alle een glasvezelstift kregen. Er werden zevenenveertig patiënten geselecteerd die een endodontische en restauratieve behandeling nodig hadden voor gebitselementen met ten minste één intacte coronale wand die was overgebleven na endodontische procedures. Bij tien patiënten werden twee gebitselementen behandeld. Als gevolg hiervan bedroeg het totaal aantal geïncludeerde gebitselementen 57. De patiënten werden willekeurig verdeeld over twee groepen overeenkomstig het soort coronale restauratie, namelijk met een metaalkeramische kroon of composietrestauratie. De klinische evaluatie werd uitgevoerd met behulp van de criteria volgens de Functional Disability Inventory (FDI). De overleving van de restauraties/gebitselementen werd geanalyseerd aan de hand van de Kaplan-Meier methode en log-rank testen. Veertien frontelementen (4 met kunsthars en 10 met kronen), 21 premolaren (12 met kunsthars en 9 met kronen) en 22 molaren (14 met kunsthars en 8 met kronen) werden gerestaureerd. Het betrof in totaal 57 restauraties (30 met kunstharscomposiet en 27 met kronen). Het recall percentage bedroeg 100% na een follow-up periode variërend van 13 tot 59 maanden, met een gemiddelde observatietijd van 29,3 maanden. Eén gebitselement werd 11 maanden na restauratie geëxtraheerd vanwege een wortelbreuk (in de composietgroep). Acht composietrestauraties en één kroon vertoonden reparabele mankementen die het gevolg waren van secundaire cariës of een restauratiebreuk. Het totale jaarlijkse faalpercentage (AFR) bedroeg 0,92% na 50 maanden voor het slagen van de restauraties, met een percentage van 1,83 voor de composietgroep en een percentage van 0,26 voor de metaalkeramische kroongroep. De log-rank testen lieten een statistisch significant verschil zien in het optreden van interventies tussen de restauratietypen (succes, p=0,022) maar geen verschil in overleving van het gebitselement (survival, p=0,344). Er werd geen verschil gevonden wat betreft het type gebitselement en de plaats in de boven- of onderkaak (p=0,970 respectievelijk p=0,797). De conclusie van de studie luidde dat restauraties die waren verricht in endodontisch behandelde gebitselementen acceptabele overlevingspercentages lieten zien, maar dat indirecte restauraties een beter klinisch resultaat en een geringere noodzaak tot een nieuwe ingreep met zich meebrachten.

Dankwoord
(Acknowledgements)

There is nothing more comforting than family. You all are so special that even with the distance and missing you, I felt the presence of my father, mother and brother just beside me. Thank you for everything.

I thank God and the Lady of Schoenstatt. I could feel your presence when needed.

To Tatiana and Maximiliano. I remember the day you asked me about the possibility of studying abroad. Thank you for everything. I've already told you that you welcomed me as parents do with their children. Hope that I overcame your expectations and our friendship keeps rising.

To my Anna, my heart. If I knew that when coming back to Brazil I would have found you, for sure one out of two possibilities would happen: the time would pass quickly or I would have return earlier. Thank you for staying with me whatever the situation is.

To the Graduate Program in Dentistry of Federal University of Pelotas and all Professors. This thesis was only possible due to all of you. Thank you for the knowledge and possibilities opened for me. For sure there is a division in my scientific life: before and after Pelotas.

Thank you to Radboud University. It is indescribable the time I experienced in Nijmegen. It's changed me, and for a better person for sure. I would like to thank everybody, but in special people that made me feel good so far from home. Marie-Charlotte, Niek, Cees, Ewald, Baas, Joost and Francis, sincerely, thank you very much. A special place in my heart and in my life are occupied by all of you.

Thank you Anelise Montagner. I believe that there is a why for everything, for better and worst things. Hopefully, I had you working/living with me during one year, which made life easier. I hope that time can unite us again.

To Rolf Winnen, for trusting me to handle a huge dataset from his private practice, which was essential for this thesis. Thank you very much.

To Franciscan University Center. Thank you for believing me as a teacher and providing me possibilities to keep growing and spreading everything that I know.

To my colleagues and students at Franciscan University Center. Good to be part of the School of Dentistry and know that I can count on all of you. Hope to fill the expectations of all of you always.

To Capes, for financial support.

To all that were not cited but are important to me or supported me in anytime of my life. Thank you for everything.